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ORIGINAL ARTICLES

ROLE OF MICRO-ORGANISMS IN THE MAKE UP OF SOIL FERTILITY. I

By S. V. Desai and W. V. B. Sundara Rao, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 3 March 1945)

SOIL is one of the major factors that influence the yield of crop. The fertility of a soil is usually taken to mean as the crop producing power under proper weather conditions. A large part of the agricultural operations is directed towards raising this productive capacity. Physical texture, chemical composition and proper bacterial flora usually play a very significant role towards determining the fertility status of the soil. The addition of organic matter and its subsequent effective utilization, definitely raises the fertility of soils, especially of the Indian soils where the content of organic matter is very low.

The soil organic matter, part of which is reduced in the soil to a colloidal state, serves as a powerful adsorbant of bases and functions as store-house of energy for micro-organisms. The micro-organisms decompose the organic matter and obtain the energy essential for their life activities. This process leads to the availability of plant nutrients.

To understand the role of the micro-organisms in the final make up of soil fertility, a micro-biological study of their numbers, kinds, activities and seasonal variations in differently manured plots possessing different productive capacities would be generally necessary. In the present studies the evolution of CO_2 was taken as an index of the microbiological activities since CO_2 evolution is an outcome of microbiological activity and is the sum total of the various effects which affect the activity at the time of sampling.

The formation of carbon dioxide in soils, without added organic matter, such as straw and farm-yard manure was studied by Lemmerman and Weissman [1924] who determined the daily yield of carbon dioxide for a period of three years and the authors deduced an equation which accurately expressed their results. The question of the decline in the rate of carbon dioxide evolution which occur when the soil was subjected to laboratory conditions was examined in some detail by Bal [1926] who showed that it was due neither to the exhaustion of the supply of organic matter nor to the formation of the toxic bodies. Corbet [1931] attempted to measure the microbial activities of the soil by a method entailing estimation of carbon dioxide evolved from soils in the laboratory. Earlier investigations carried out at the Imperial Agricultural Research Institute, Pusa (Scientific Reports of the Institute, 1931-32, p. 148) in which soil microbiological activities were studied by the amounts of CO_2 evolved after the addition of oilcake very little difference showed in the decomposition of oilcakes, in spite of variation in yields.

In the present investigation an attempt was made to examine how the rates of the evolution of carbon dioxide in the soil samples of same plots of the permanent manurial series 'Pusa' varied with treatments and how these were related to the yields of the plots. The first series of studies by the senior author, Biswas and Dutta from 1940 to 1941 were made with these soils which were incubated at the laboratory temperature and the data obtained showed a general agreement between crop yields and microbial activity measured by the amount of CO_2 estimated in 10 days.

In the present investigation, the soil samples collected in summer, monsoon and winter of 1941 and spring samples of 1942, were studied. The amount of CO_2 evolved was determined by incubating the soils collected in the different seasons, at constant temperature of 34°C. to observe, if seasonal differences in the microbial activities *in situ* were reflected in the microbial activities, when measured in the laboratory at constant temperature of incubation. The data so obtained denoted that the differences in the activities in different seasons were due to difference in the kinds and number of microflora that persisted in dry soils and functioned under optimum temperature and moisture conditions. Since the plots differing in fertility would add year after year crop residues in quantities in

the same order as the order of fertility, the agreement observed between CO_2 evolved from the plots and the crop yields may be due merely to the differences in organic matter content in these plots and may not be due to microbial activities as such. Hence the carbon content of each of the soil samples was determined and the respiratory power of the soil was expressed as the amount of CO_2 evolved per 100 parts of carbon in the soil. This would eliminate the differences due to the different amounts of organic matter in the soil of the plots of different treatments and express differences in microbial activities as such. The data obtained were examined as to seasonal variations and compared with crop yields of the plots.

The Pusa permanent manurial series were started in 1908 and the plots were manured according to a fixed programme since then, each plot receiving a particular type of manurial treatment continuously. Definite fertility levels have been established in these plots as reflected by yields. The plots selected for investigation were 3A (F.Y.M.), 7A (K_2SO_4), 10A (N+P+K), 12A (Green manure), 13A (Check) and 16A (Green manure and Super). The details of the treatments regarding the actual quantities of manures applied, rotation practised and the dates of manuring are given in Appendix I.

1. *Dates of taking soil samples and state of the plots*—(Samples collected on 25 April and 13 September 1941 were collected by Biswas and Dutta, the colleagues of the authors). *Samples collected on 25 April 1941*—Barley was the crop in the plot 12A while *rahar* was the crop in the rest. *Rahar* was just harvested.

2. *Samples collected on 13 September 1941*—Maize was sown in the middle of June in plots 3A, 7A, 10A and 13A. The crops were standing in the field. In plots 12A and 16A green manure had been buried 6 weeks before. There was no standing crop in these plots when samples were taken. Maize was harvested after 15 days.

3. *Samples collected on 1 December 1941*—Fertilizers were applied on 19 October 1941. *Rabi* crop (wheat) was sown on 22 October 1941. The crop was in early stages of growth. The variety of wheat used was I.P. 52.

4. *Samples collected on 2 March 1942*—Wheat was the crop in all the plots and it was to be harvested in April. This time duplicate composite samples were also collected by gently removing the soil sticking to the plant roots.

EXPERIMENTAL

The samples were taken from the borings (0-6 in. depth) from each plot and composite samples were prepared therefrom. The borings were taken at the centre of each alternate square, after dividing the plot into 15 equal squares, the size of each plot being 1/4 of an acre.

In December 1941 and March 1942, duplicate composite samples were obtained, with a view to evaluate the variation in biological activity between the two composites of the same plot. The second composite was made by mixing the samples taken from the borings at the centres of the other alternate squares. The samples collected were air dried and sieved through 60 mm. sieve.

Water (16 cc.) was added to 100 gm. portion of each soil sample to have the moisture equivalent to 1/3 saturation capacity which was optimum for these soils. The soil was well-mixed and placed in conical flasks of 1,000 cc. capacity and fitted with two holed rubber corks, carrying in one hole a long glass tube extending nearly to the bottom of the flask and in the other a short glass tube extending just through the cork. Both the glass tubes were bent at right angles. The flasks were sealed with paraffin wax, the rubber connections, attached to the free ends of the glass tubes, were closed with screw clips and glass rods were inserted at the ends of rubber tubings to prevent leakage. The flasks were incubated at 34°C. CO_2 evolved was determined periodically for 10 days (daily for 4 days and on alternate days for the remaining 6 days) by aspirating $2\frac{1}{2}$ litres of air washed free from CO_2 each time through these flasks at the rate of 1,000 cc. per hour, absorbing the CO_2 evolved in known amounts of barium hydroxide kept in Pettenkofer's absorption tubes, and back-titrating with N/10 HCl using phenolphthalein as indicator.

The question whether the air which was aspirated should be passed through the soil or over the surface of the soil had to be settled to suit the convenience. As the layer of soil in a litre flask was hardly an inch deep, it was considered that air drawn from the surface without disturbing or aerating the soil was preferable as the activity of micro-organisms would be normal under these conditions. The aeration through the soil has been known to lead to abnormal activity and increase in CO_2 production. Further taking into consideration that the CO_2 evolved was determined daily till the rate of evolution was reduced to 1·5 to 2 mgm. per day, the soil was taken to be kept under natural conditions.

The flasks were wrapped in black paper to avoid the effects of light. The standard error obtained with 4 replications of a sample was only 1·5.

TABLE I

CO_2 evolved in 3A plot soil sample (March sample)

	CO_2 evolved in mgm. per 100 gm. of soil
Aliquot 1	44·7
Aliquot 2	48·1
Aliquot 3	46·66
Aliquot 4	46·6
Mean	46·5 (±1·5)

In the present study a difference over 3 mgm. was taken to be significant. Further it was observed that the same value was obtained for the amount of CO_2 evolved in the same soil sample even when the determinations were made six months or nine months from the date of air drying and sieving denoting that comparative studies can be made with such soil samples even when the determinations were made on different dates but under similar experimental conditions of temperature and moisture.

TABLE II A

CO_2 determined in soil sample from plot 3A

	CO_2 in mgm. per 100 gm. of soil
1 Six months after taking the sample	46·5
2 Nine months after taking the sample	44·5

Good agreement was observed between amounts of CO_2 evolved in duplicate composites.

TABLE II B

Showing variation in CO_2 evolution in duplicate composite samples

Plot No.	Treatment	CO_2 evolved in mgm. per 100 gm. of soil		
		1st composite	2nd composite	3rd composite
3A	F.Y.M.	44·4	41·4	42·9
7A	K_2SO_4	32·6	30·0	31·3
10A	N-P-K	39·6	36·96	38·28
12A	G.M.	35·8	32·2	34·0
13A	Check (unmanured)	27·7	28·6	28·16
16A	G.M. and Super	50·6	50·4	50·5

Throughout the course of the work duplicate determinations were made and the mean was taken as the amount of CO_2 evolved.

Seasonal variations—Tables III and IV show the amount of CO_2 obtained from the soil samples taken on different dates and the respiratory powers of the soils expressed as the amount of CO_2 evolved per 100 parts of carbon respectively.

TABLE III

Amount of CO_2 obtained for the soil samples taken on different dates

Plot No.	Treatment	CO_2 evolved in mgm. per 100 gm. of soil in 10 days			
		Summer	Monsoon	Winter	Spring
3A	F.Y.M.	66	48	36	43
7A	K_2SO_4	..	28	22	31
10A	N-P-K	64	40	34	38
12A	Green manure	44	33	26	34
13A	Check	46	30	24	28
16A	G.M.—Super	65	48	36	51

TABLE IV

Respiratory powers of the soil

Plot No.	Respiratory powers of the soil			
	Summer 96·3°F.	Monsoon 80·6°F.	Winter 64·6°F.	Spring 76·4°F.
3A	17·3	13·1	8·7	10
7A	11·6	8·2	6·0	8·9
10A	14·2	11·4	7·3	10·5
12A	9·7	9·2	6·7	9·1
13A	12·3	8·4	7·1	8·5
16A	14·7	11·2	8·6	13·5

The temperatures mentioned in each season represent the average temperatures during the month in which the samples for the season were taken. Data on temperatures were obtained through the courtesy of Dr B. P. Pal, *Imperial Economic Botanist, Indian Agricultural Research Institute, New Delhi.

From the above Tables (III and IV) it can be seen that, though all the samples were incubated at the same temperature and moisture, the samples taken in summer evolved the largest amount of carbon dioxide while winter samples evolved the least amount. The respiratory powers of the soil samples, also were higher in summer than in winter. Irrespective of treatments the seasons affected similarly the rate of decomposition of soil organic matter in the different plots. In plots of low fertility, 7A, 12A and 13A, where the general nutrient supply was low, the respiratory powers in monsoon and spring, when the temperatures did not vary much, were nearly equal. In plot 16A (G.M. + super-treated plot) the green manure was ploughed under in mid-July. By March, the

* Now Head of the Division of Botany, Indian Agricultural Research Institute, New Delhi.

green manure decomposed and mineral nutrients were present in the soil in abundance. As such, the respiratory power in spring was definitely higher than in monsoon. A comparison of summer, monsoon and winter samples showed a definite fall in respiratory powers with fall in temperatures. From this it appears that the prevailing variations in temperatures in the plots, when the samples were taken have introduced variations in the activities of the organisms in the soil samples of the different plots which could be observed even when the activities were measured under similar conditions of moisture and temperature.

Micro-biological activities of organisms near the roots and away from the roots as denoted by CO_2 evolution—The work of Lochhead [1940], West and Lochhead[1940] and West[1939] support the view that plants secrete amino-acids and growth-promoting substances which enhance the bacterial activity and hence exhibit the Rhizosphere effect. Determinations of the rates of CO_2 evolution of the spring soil samples, from the root zone and away from roots, were made to examine whether any distinct difference was obtained.

The following Table shows the amounts of CO_2 evolved in the soil samples taken from the roots (Rhizosphere) and away from the roots (Arhizosphere).

TABLE V

CO_2 evolved in mgm. per 100 gm. of soil

Plot No.	Root zone (Rhizosphere)	Away from the root zone (Arhizosphere)
3A	77	43
7A	55	31
10A	71	38
12A	62	34
13A	57	28
16A	82	51

From the above it can be seen clearly that larger amount of CO_2 was evolved by soils from rhizosphere than from arhizosphere. It remains to be proved whether this high evolution was due to stimulation of the activities of the micro-organisms, or alteration in the kinds of micro-organisms near the roots by plant secretions or due to large amount of organic matter present in the rhizosphere. It was suggested by various workers Lundegardh [1925]and Livingston [1934] and others that carbon dioxide of the soil atmosphere was a good source of carbon for plants. It may be that the widely different amounts of CO_2 produced near the roots in the different plots contributed to some extent to the differences in yield of crops of these plots.

TABLE VI

CO_2 evolution and crop yield—Kharif *crop—maize*

Plot No.	Treatment	CO_2 evolved in mgm. per 100 gm. of soil Monsoon samples	Yield of 1941 (lb.)	Average yield (1930-42)
3A	F.Y.M.	47·7	1,326	1,344
7A	K_2SO_4	28·0	108	410
10A	N-P-K	40·0	909	875
12A	Green manure	33·0	G.M.	G.M.
13A	Check	30	130	319
16A	Green manure and Super	47·5	G.M.	1,026
	Coefficient of correlation	..	±0.9786	±0.9506

TABLE VII

CO_2 evolution and crop yields—Rabi crop—wheat

Plot No.	Treatment	CO_2 evolved in mgm. per 100 gm. of soil (Spring samples)	Yield of (1941-42) lb. crop wheat	Average Yield (1930-31 to 1941-42) lb.
3A	F.Y.M.	43	867	922
7A	K_2SO_4	31	233	419
10A	N-P-K	38	689	945
12A	G.M.	34	367	500
13A	Check	28	223	365
16A	G.M. and Super	51	1,350	1,386
	Coefficient of correlation	..	±0·98992	±0·96605

TABLE VIII *

Per cent increase in CO_2 evolved over check

Plot No.	Monsoon		Winter		Spring		Range	Average of *kharif* and *rabi* yields
	Differ-ence	Increase	Differ-ence	Increase	Differ-ence	Increase		
3A	17·7	59	12·1	50·6	15	53·6	50-60 II	1133 II
7A	—2	—6·6	—2·2	—9·2	3	10·7	—10-10 V	415 V
10A	10	33·3	9·6	40·2	10	35·7	30-40 III	910 III
12A	3	10	2·2	9·2	6	21·4	10-20 IV	500 IV
16A	17·5	58·3	12·4	51·9	23	82	50-80 I	1,206 I

Carbon dioxide evolution and crop yields. Table VI shows the amount of carbon dioxide evolved in samples taken in monsoon, the yield of the then standing crop, maize, and also the average *kharif* yield for the last 12 years. Table VII shows the amount of carbon dioxide evolved in spring samples and the *rabi* yields for 1941-42. The last column denotes the average for the last 12 years. The percentage increase in CO_2 evolution from the soil samples from the different plots over that of the check plot were entered in Table VIII.

*The yield data for 1941 and 1942 were obtained through the kind courtesy of the Imperial Economic Botanist. The average yields of the plots were evaluated from the Annual Scientific Reports of the Institute. The permanent manurial series at Pusa were conducted by the Imperial Agriculturist up to 1935-36 and thereafter by the Imperial Economic Botanist.

Discussion

Fertility levels in the different plots—The permanent manurial series at Pusa have been in progress for over 35 years. They were conducted by the Imperial Agriculturist* up to 1935-36 and thereafter by the Imperial Economic Botanist. After leaving a margin of about 20 years when the fertility status of these plots can safely be considered to have been well-established, the average yields of 12 years (1930-1941) and the general trend of yields were taken into account in determining the fertility levels of these plots.

From the yield data given in Table IX it can be seen that of the plots under study the unmanured plot 13-A, potassium sulphate-treated plot 7-A, and the green-manured plot 12-A were of low fertility and the plot 10-A receiving complete minerals (N+P+K), the farmyard manure-treated plot 3-A and the green manure and super-treated plot 16-A were of high fertility.

In view of the difference in the practices adopted in *kharif* and in *rabi*, the levels of fertility of the more fertile plots 3-A, 10A and 16-A in *kharif* varied slightly from those in *rabi*. The yield of farmyard manure-treated plot 3-A which was the highest in *kharif* fell down nearly to the level of the yield of the NPK treated plot during *rabi*. This was due to the fact that in the former plot the farmyard manure was applied to the *kharif* crop and the residual effect was only available for crop growth in *rabi*. The green manure and super-treated plot had maize in *kharif* in one year alternated by a crop of green manure raised with superphosphate as fertilizer-ploughed in mid-*kharif* of the succeeding year. As such, the direct effect of green manure and super was on the *rabi* crop following the *kharif* green manuring while the residual effect was observed on the succeeding maize crop. So in *kharif*, the yields of this plot were lower than that of the farmyard manure-treated plot. In *kharif* when arranged in the descending order of fertility, farmyard manure-treated plot occupied the first place followed by green manure and super-treated plot. The plot treated with complete minerals (NPK) showed the best yield among the fertile plots.

One interesting point that emerged from these long range experiments was that manuring with organic against inorganic materials maintained soil fertility at a high pitch for one season and after the mineralization of the organic material the fertility came almost to the same level as the complete mineral plot, as seen in the residual effects in farmyard manure-treated plot and in green manure and super-treated plot.

Judging from *rabi* yields in general, the plots of high fertility were in the following descending order of fertility (i) G.M. and Super, (ii) N P K and (iii) Farmyard manure. Considering the *kharif* and *rabi* yields together, maximum yields were recorded by the G.M. and Super-treated plot, followed by F.Y.M.-treated plot and the plot receiving complete minerals (N P K).

Kharif	Order of fertility	
	rabi	*kharif* & *rabi*
Plot 3A (F.Y.M.)	Plot 16-A	16-A
16A (G.M. & Super)	19-A	3-A
10A (N P K)	3-A	10-A
12A (G.M.)	12-A	12-A
7A (K_2SO_4)	7-A	7-A
13A (Unmanured)	13-A	13-A

*Now Head of the Division of Agronomy.

The data presented in Tables VI and VII denote that the crop yields in the different plots were parallel to the soil microbiological activities. The amount of carbon dioxide evolved from the complete minerals treated plot in spring samples was slightly less than what it should be to denote the level of fertility established in this plot from the average *rabi* yields. However, it denoted the fertility status of the plot in *rabi* of the year in which the sample was taken. The respiratory powers of the soils from the fertile plots during each of the four seasons were higher than those of the soils from the infertile plots and the order of the respiratory powers were in general also the order of yields (compare Tables IV, VI and VII).

Further the data in Table VIII show that definite levels of fertility were established in the microbial activities of these plots irrespective of seasons, corresponding to the levels of fertility as judged from the average yields of the last 12 years for *kharif* and *rabi*. The different fertilizer treatments given in these plots established differences in the microbial activities simultaneously introducing differences in the yields.

The results of Bottomley and Mockeridge [cited in Shopfer, 1943] led to the conclusion that development of higher plants was stimulated by organic substances of microbial origin. Viswanath [1932] reported that organic manures increased crop yields over those obtained from mineral fertilizers and the seed of plants treated with organic manures had greater vitality and produced superior plants. The work of Rowlands and Wilkinson [1930] and Hartley and Green Wood [1933] confirmed the results of McCarrison and Viswanath [1926]. However this aspect was still debated as to its applicability in all cases. Harris [1934] and Leong [1939] could not find any appreciable difference in thiamine content of grain from manured and mineral fertilized soils of the Rothamsted plots. The results of Scheunert [1939-40] indicated that the type of the fertilizer treatment had little or no effect on the amounts of vitamin contents in the plants. While Starkey [1944] recognized the possibility that vitamins and other organic substances contained in soils and originating from microbial development have important effects on higher plants, he believed that the likelihood of obtaining superior plants simply as a result of adding vitamins to soils was remote.

In the present investigation the beneficial effects of organic manures in Pusa soil were clearly seen from a comparison of the *kharif* yield data where the direct effect of the organic manure was in evidence in plot 3-A and the yields of this plot were definitely better than those in the complete minerals treated plot 10-A. Similarly in *rabi* the yields of cereals from the green manure *plus* super-treated plots (where the direct effect of organic manuring was in evidence) were better than those from the complete minerals treated plots (where the effects of mineral manuring were in evidence).

It is known that in the soil plant nutrients are brought into available form by microbial action. In the light of these observations, close association of the levels of soil microbiological activities in the different plots with the fertility levels of these plots, though partly due to the similarity in the conditions — temperature, moisture, aeration and presence of nutrients — essential for plant growth and microbial activities, indicates that the plants for their vigorous growth in soil depend to a considerable extent on the activities of micro-organisms, in addition to their own powers of absorption, for the supply of the plant nutrients, and micro-organisms play an intimate role in the make up of soil fertility by supplying these nutrients.

The treatments which enhanced microbial activity also raised the soil fertility. So the beneficial effect of the addition of fertilizers appears to be at least partly due to enhancing the microbial activity and consequently releasing the plant nutrients in available form. From this the possibility of judging the manurial needs of soils by responses in CO_2 evolution to the addition of fertilizers was envisaged. Studies conducted in this respect will be discussed in Part II of the paper.

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Appendix I

Plots and Treatments

The plots from which the soil samples were taken are 3A, 7A, 10A, 12A, 13A and 16A of the permanent manurial (old) Series Punjab Field, Pusa, each of which has been receiving the same type of treatment for over 30 years.

Area of each plot $\frac{1}{4}$ acre

The treatments are as under :—

Plot No. 3A . . .	Farmyard manure at 8,000 lb. per acre (before sowing *kharif* crop, *i.e.*, in early June).
Plot No. 7A . . .	K_2SO_4 at 50 lb. K_2O-$\frac{1}{2}$ in *kharif* $\frac{1}{2}$ in *rabi*.
Plot No. 10A . . .	K_2SO_4 at 50 lb. K_2O, Super at 80 lb. P_2O_5, $(NH_4)_2\ SO_4$ at 40 lb. N—($\frac{1}{2}$ in *kharif* and $\frac{1}{2}$ in *rabi*).
Plot No. 12A . .	Green manure in conjunction with purely cereal rotation (G.M. sowing in early June, burying in late July).
Plot No. 13A . . .	Check Plot.
Plot No. 16A . . .	Effect of green manure and leguminous crop in the rotation with an additional application of super at 80 lb. P_2O_5 with G.M. (G.M. sowing is done in early June, and super is added at the same time. G.M. is buried at the end of July).

Rotation practised	*kharif*	*rabi*
1st Year	Maize	Barley
2nd Year	,,	*Arhar*
3rd Year	,,	Wheat
4th Year	,,	Peas

Plot 12 had G.M. grown and ploughed in during *kharif*.

Explanatory note on treatment of plot 16A—In 16A, in one year, G.M. is sown, and ploughed in during *kharif*. Wheat or barley is sown as *rabi* crop. In the next year (about June) maize and *arhar* are sown together.

Maize is cut in October while *arhar* is cut in April. In the succeeding year during *kharif* green manure crop is sown and ploughed in.

B

TABLE IX

Permanent Manurial Series (Pusa) Old Punjab Field, Rabi-*yield in lb.*

Plot and Treatment	Peas	Barley	Rahar	Wheat	Peas	Barley	Rahar	Wheat	Peas	Barley	Rahar	Wheat	Average
	30-31	31-32	32-33	33-34	34-35	35-36	36-37	37-38	38-39	39-40	40-41	41-42	
13A Check	328	400	640	412	280	608	321	412	52	299	400	228	365
3A F.Y.M.	764	1,460	1,191	1,820	1,073	460	1,103	1,049	218	1,010	544	867	928
10A N+P+K	534	1,876	1,211	984	1,084	668	1,078	1,246	30	1,936	507	689	945
12A G.M.	575	493	859	552	852	646	510	506	160	374	109	367	500
	(Barley)	(Wheat)	(Barley)		(Barley)	(Wheat)	(Barley)		(Barley)	(Wheat)	(Barley)		
16A G.M.+Super	714	2,807	665	2,060	922	2,476	1,028	1,687	318	2,048	552	1,350	1,386

Kharif—Maize Yield in lb.

Year	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	Average
13A Check	230	753	107	411	918	292	296	199	..	406	81	130	319
3A F.Y.M.	1,807	1,141	1,306	690	1,457	2,100	1,662	980	415	1,830	1,413	1,326	1,344
10A N+P+K	1,692	1,203	584	673	914	948	1,078	1,249	60	498	693	909	875
12A G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.	G.M.
16A G.M.+Super	1,092	G.M.	994	G.M.	1,909	G.M.	1,448	G.M.	17	G.M.	693	G.M.	1,026

ROLE OF MICRO-ORGANISMS IN THE MAKE UP OF SOIL FERTILITY PART, II

STUDY OF THE RATE OF CO_2 EVOLUTION AS A METHOD FOR DETERMINING THE MANURIAL NEEDS OF A SOIL

By S. V. Desai and W. V. B. Sundara Rao, Imperial Agricultural Research Institute, New Delhi

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(With two text figures)

ARABLE soils contain the organic remains of previous crops together with excretions produced during their growth. Their bacterial flora is diverse, and the activities and processes which take place within the soil, physical, chemical and biological, are exceedingly complex. It is the sum total of these activities and their products that determine largely the fitness of a soil for plants. rather than the variation in the character and composition of its mineral matter. While manure and fertilizers may often increase crop yields as a result of a direct supply of plant food or as a stimulant to the plants, there is now abundant evidence that their effect is rather the results of a direct action upon the soil, thereby changing its relation to plants. Complex and imperfectly understood as is their action, this is a more satisfactory explanation of the benefits derived from fertilizers than the idea that the inconsequential amounts of nitrogen, potash and phosphorus supplied, as compared with the larger stores of those elements already in the soil, should be directly responsible for marked increase in growth frequently following the application of fertilizers.

At present there is no easy method of judging the fertility of a soil or determining the soil deficiencies for plant nutrition. The only criterion of soil fertility is crop yields. The crop yields are dependent upon the climatic variation during the period of growth, and if weather conditions are not favourable in any particular year, the yield of that year does not indicate soil fertility. Under these circumstances the average crop yields of a field can only indicate the productive capacity of the field. These observations. therefore, take years to be of value. The life-cycle of agricultural crop takes at least three months. The seasonal variations are such that the same crop can be raised usually only once in a year. Thus the determination of soil fertility for a crop would take very long time to give practical results. Under these circumstances, various methods have been devised to find out the plant nutrients available in the soil by chemical determinations and several biological methods have been suggested to find out the soil deficiencies.

Chemical methods : Based on the hypothesis that plant roots, due to the acidity produced by their activity, can extract plant food from the soils, earlier attempts were made by Dyer [1894] to determine the available nutrients in soil by using either carbonic acid, dilute HCl, acetic acid or citric acid as an extracting agent. Since then these methods have been developed and further methods have been devised based on extraction by chemical reagents.

Physiological Methods : Among the methods in which plants have been used as extracting agents for available plant food materials in the soil, Neubauer's method [1929] in which rye seedlings are used, is the most outstanding. Neubauer's assumption that the quantity of root soluble potash and phosphoric acid obtained by this method is a natural soil constant is however not borne out by experiments as it depends on a number of other factors, among which the plant species and the variety used as extracting agents are important. Strict control of temperature is essential according to Neubauer.

Microbiological methods : Based on the assumption that the microbial activity and soil fertility are interrelated and a direct correlation exists between these, attempts have been made to examine (*a*) the ammonifying power, (*b*) nitrifying power, (*c*) nitrogen-fixing power of the organisms of the soils to suggest the fertility level. Next reasoning that the general requirements of micro-organisms and plants are similar, direct methods have been evolved in which cultural experiments are conducted with bacteria.

For determining available nitrogen in soil, Waksman and Heukelekian [1924] worked out a method based on the cellulose decomposing power of a soil. Asotobacter tests due to Christensen [1911] are adopted for diagnosing lime and phosphate deficiencies.

The main drawback of the Cunningkamella and Aspergillus methods (Smith *et al*, 1935) is that the weight of the mycelium is not a direct measure of the nutrient. It is necessary to draw a graph showing the relationship between the weight and composition of the mycelium.

Though the growth of the organisms is limited by the phosphorus supply, in determining the needs of a soil by azotobacter method we are considering more the phosphorus needs of azotobacter for nitrogen-fixing power, than the P needs of the general bacterial flora. The assumption made here is that P needs of azotobacter are more than those of other organisms and if azotobacter grows well with the particular soil as a source of P, then the P needs of other organisms are met. But if the response of the general bacterial flora can be determined and at the same time indications as to the extent of their activities can be obtained, it would be easy to picture the rate of supply of plant nutrients and at the same time determine the N, P, K needs of a soil.

In a separate paper on the Role of Micro-organisms in Soil Fertility-I, it was shown that good correlation existed between the crop yields of the differently manured plots and the amount of CO_2 evolved from the soils of the respective plots under standard conditions of temperature and moisture. From the results obtained, it was concluded that the soil micro-organisms play an intimate role in the make up of soil fertility.

If the effect of the additions of N, P or K to the soil is to accelerate the rate of decomposition of soil organic matter either by their stimulating action on micro-oganisms or by their chemical interaction with the organic matter and making it amenable for microbial attack, then it can be expected that by add ng N, P or K either singly or in different combinations to the check plot soil samples, and by determining the amounts of CO_2 evolved, indications can be obtained as to the N, P or K needs of the soil from the responses in the microbiological activity (amounts of CO_2 evolved) to these additions.

Experimental

The following sets were set up with summer, monsoon and spring check plot soil samples (brought from plot 13A Punjab Field Permanent Manurial Series) and the amount of carbon-dioxide evolved was determined in each of these soil sets for a period of 10 days.

Sets :—

1. Soil
2. Soil plus K_2SO_4 (Equivalent to 15 mgm. K_2O per 100 gm. soil)
3. Soil plus Super (equivalent to 30 mgm. P_2O_5 per 100 gm. soil)
4. Soil plus Ammonium nitrate (NH_4NO_3 equivalent to 30 mgm. N per 100 gm. soil)
5. Soil plus Super plus NH_4NO_3 (in amounts as above)
6. Soil plus Super plus NH_4NO_3 plus K_2SO_4 (in amounts as above)

Details of technique : The air dried soil samples were sieved through 60 mm. sieve and water along with the necessary fertilizers was added to 100 gm. portion of each soil samples to have the moisture equivalent to 1/3 saturation capacity which is the optimum for Pusa soil. The amount of CO_2 evolved from 100 gm. of soil in 10 days was determined as described in Part I.

The amounts of N, P, K added were such as to show response, if at all, the addition of these elements were to affect the rate of decomposition. Table I shows the results obtained with these additions to the summer check plot sample and the yields for *kharif* and *rabi* seasons of the plot, receiving the corresponding treatments.

TABLE I

CO_2 evolution and yields

Plot-13A Check (Laboratory additions)	CO_2 evolved in mgm.	Plots field treatments	*Rabi*		*Kkharif*—Maize	
			1941-42 yields wheat grain (lb.)	average yields 1930-31 to 1941-42 (lb.)	1941 yields (lb.)	average yields for 12 years (lb.)
Soil	46	13A Check	223	365	130	319
Soil plus K	47	7A K_2SO_4	233	419	109	410
Soil plus P	59	8A Super	510	868	650	663
Soil plus N	42	6A $(NH_4)_2SO_4$	233	444	271	420
Soil plus N plus P	59	11A (plus P)	644	933	801	458
Soil plus N plus P plus K	55	10A (N plus P plus K)	686	945	909	875

Co-efficient of correlation—

Between columns 2 and 4 . . . . $\pm 0{\cdot}74$
Between columns 2 and 5 . . . . $\pm 0{\cdot}77$
Between columns 2 and 6 . . . . $\pm 0{\cdot}7$

DISCUSSION OF THE RESULTS

The activities of the micro-organisms which result in a change of the minerals from one chemical state into another can be classified as follows: (i) Heterotrophic energy utilization of micro-organisms lead to a mineralization of the soil organic matter or to the liberation of plant nutrients, from their combination with organic compounds. (ii) A part of the minerals thus liberated, or added to the soil in the form of inorganic fertilizers will be reassimilated by various soil organisms and change from a soluble into insoluble condition. (iii) The autotrophic bacteria utilizing minerals as a source of energy, bring about a change in the chemical nature of the minerals in question. (iv) The interaction between insoluble minerals in soil with the products formed by the activities of the micro-organisms, especially organic and inorganic acids, result in an increase in the solubility of these minerals.

Phosphorus: A large number of micro-organisms including various fungi and actinomycetes, are capable of decomposing organic phosphorus compounds. Insoluble tri-calcium phosphates may be brought into solution by microbial action in three different ways, (i) by direct metabolism of the micro-organisms, perhaps through the formation of some enzyme or by interaction with some synthesized substance, (ii) by the action of carbon dioxide as well as various organic acids produced by soil organisms and (iii) by the action of the inorganic acids formed in the metabolism of the autotrophic nitrifying bacteria and sulphur oxidising bacteria. The actual amount of soluble phosphate in soil depends not so much upon the number of micro-organisms as upon their kinds and is determined by the total phosphorus compounds, soil reaction, presence of available energy and nitrogen.

Potassium: The activities of bacteria lead to an increase in the available potassium, as in the decomposition of organic matter by micro-organisms, and in the formation of acids which liberate potassium from zeolites.

Nitrogen: In the presence of available carbohydrates two factors are at work. (1) Less of the protein is decomposed since the bacteria and fungi prefer the carbohydrates to the protein as a source of energy. (2) The ammonia that has been formed from the decomposition of proteins may be reassimilated by the micro-organisms which utilize the carbohydrates as a source of energy. These

microbes are therefore competing with higher plants for the available nitrogen compounds in the soil. In the presence of undecomposable organic matter, the soluble nitrogenous salts are transformed into insoluble proteins, these compounds are decomposed later and make the nitrogen compounds available again.

From the above theoretical considerations, it can be assumed that the soil micro-organisms through their life processes play an intimate role in determining the amounts of the available nutrients in the soil at any particular time. The results obtained in this investigation (Table I and Table II denote the responses in CO_2 evolution to N, P, K additions to check plot soil sample on different occasions) indicate that differences had been established in microbiological activities as denoted by the different amounts of carbon-dioxide evolved, due to the addition of N, P or K either singly or in different combinations.

TABLE II

CO_2 evolution with and without the addition of N, P, K to the check plot soil samples of summer, monsoon and spring

Plot 13A Check (unmanured) Plot sample	CO_2 evolved in mgm. per 100 gm. of soil		
	summer	monsoon	spring
Soil	46	30	28
Soil+K	47	34	34
Soil+P	59	36	38
Soil+N	42	21	29
Soil+N+P	59	*32	36
Soil+N+P+K	55	36	34

*KP.

When this observed fact is viewed in the light of the above ideas, it may be suggested that these differences in microbiological activities are likely to lead to differences in the amounts of plant food made available to the plant. If this hypothesis is correct, then we expect that the crop producing powers of the plots to which N, P or K are added in different combinations should be predictable from the amount of carbon-dioxide evolved in the check plot soil sample on the corresponding addition of these elements. It was observed from Table I that good responses in the amounts of carbon-dioxide evolved from the check plot soil sample, were obtained by the additions of P N P and N P K. The addition of K did not affect this rate, while that of N showed slight depression. Broadly speaking these values can be put in two classes—one representing the addition of P either singly or in different combinations, and the other the addition of K or N, the former class showing the greatest response, and latter either none or slight depression. The definite rise in the amount of carbon-dioxide evolved due to the addition of P to the check plot soil sample was accompanied by the definite responses in yields to the addition of P in the plots either singly or in combination with other elements.

The slight depression or definite lack of response in carbon-dioxide evolution when N was added was due to the narrowing of effective C/N ratio and this suggested that there was very little of easily decomposable organic matter in the soil or in other words, the soil contained a low amount of available carbon and a relatively high amount of available nitrogen. This can be taken to denote, that the addition of organic matter to the soil was necessary. The manurial need of the soil as indicated by these studies (response to P and depression to N) is that P should be added along with organic matter or P in an organic form should be added. It can be seen from the yield figures (Table III) that the farmyard manure treated plot and green manure + super treated plot recorded the highest yields.

TABLE III

Plot	Treatment	*Rabi*		*Kharif*—Maize	
		1941-42 yields wheat grain lb.	Average yields 1930-31 to 1941-42 lb.	1941 yield lb.	Average yields for 12 years (1930-42) lb.
3A	F.Y.M.	867	922	1,326	1,344
7A	K_2SO_4	233	419	108	410
10A	N+P+K	683	945	909	875
12A	G.M.	367	500	G.M.	G.M.
13A	Check	223	365	130	319
16A	G.M.+Super	1,350	1,386	G.M.	1,026

The slight response in yields to the addition of N (Table I) in the plot 6A was due to (i) the direct effect of N on crop, (ii) the increased availabity of the plant nutrients as a result of increase in rate of decomposition of increasing amounts of organic matter, which were left in the form of plant residues in the soil of this plot receiving $(NH_4)_2SO_4$ in larger quantities year after year, as compared to the additions to the check plot.

Thus from the response or depression in the amount of CO_2 evolved when nitrogen is added to the soil sample, indications can be obtained whether the soil responds to inorganic fertilizers or to organic manures rich in nitrogen or to organic manures rich in carbon.

The inclusion of K in the combination of N P did not raise the productive capacity of the soil appreciably over that of the N P treated plot (Table I). This fact was also borne out by this studies.

Thus it was observed that the manurial needs of the Pusa soil as indicated by carbon-dioxide evolution studies were the same as those suggested by manurial trials spread over a large number of years. From the studies of the responses in the rates of carbon-dioxide evolution of the check plot soil samples taken in summer, monsoon, spring (Table II) it was clear that the manurial needs of the soil were best indicated by the summer samples (samples taken soon after harvest and before subsequent ploughing). So it appeared that the soil samples taken subsequent to harvesting and before ploughing were quite suitable for denoting the manurial needs of the soil. It is exactly at this stage, that the farmer required to know the manurial need of his field.

The correlation herein observed was between two factors, soil microbiological activity on the one hand and fertility on the other, segregated from the other factors like weather conditions. Optimum conditions were maintained in determining the CO_2 evolution rate though these were rarely obtained in the field. But the fact that standard conditions were employed do not vitiate the basis of the theory, since alterations in the environments effect the microbial activity almost similarly in the different plots of the same locality.

In the methods previously proposed to assess soil fertility and suggest manurial needs, either the amounts of available nutrients in the soil at the time of study were determined by chemical methods or the rates of availability of these were estimated by biological methods such as azotobacter plaque technique. or the intake of the nutrients was measured by growing a selected species of plant. The serious objection to the first method is that the available amount of nutrients N, P or K in the soil is not a constant factor and is subject to frequent changes. The ever changing status of available plant nutrients as a result of microbial activity is more and more rapidly being recognized.

What is required is the rate of the synthesis of plant food rather than the mere amount at any particular instance. The present proposed method, in addition to denoting the rate of microbial activity and as such the rate at which the plant nutrients are made available, indicates the requirements of N, P, K or organic matter for the soil to be raised to a high level of fertility. The indications

obtained are the result of growing a crop of micro-organisms under strictly controlled conditions and hence is equivalent to growing crops to obtain the manurial requirements of a soil, without the disadvantages of prolonged investigation, effects of changes in the weather conditions and several other varying factors.

It is always advisable to take samples for studying CO_2 evolution after the added organic manures in the plots have decomposed. Then only the relative rates of decomposition of soil organic matter which bear any relationship to yields can be obtained. Otherwise account should be taken of the added organic manure before inferences are drawn. Earlier investigations carried out in this laboratory [Scientific Reports of the Imperial Institute of Agricultural Research, Pusa, 1931-32, p. 148] when oilcake was added, denoted very little difference in the decomposition of added oilcake as regards CO_2 production in spite of variations in yields. These studies showed only the rate of decomposition of the added organic material without reference to the rate of availabilities of plant nutrients as a result of the decomposition of soil organic matter. Similarly in the work of Andrew [1935] success was not achieved in cases where attempts were made to determine soil manurial needs by adding fertilizers and studying the relative rates of decomposition of added glucose to the soil. [C.W.B. Andrews, 1935] The best method of judging the manurial needs of soil appears to be to determine the responses in the rate of decomposition of soil organic matter, to the addition of fertilizers, without adding any extraneous available source of energy.

Samples of barley grain were obtained from the permanent manurial series, Pusa and were analyzed for N and P constituents to examine whether the supply of a deficient mineral in the soil had actually led to an increase in that element and other elements as well in the crop. The total amounts of these recovered into the grain of the crop from each plot and the percentage increases over check were calculated and the data were entered in Table IV. From this Table it is clear that the percentage increases over check in N and P in the grain were more from the plot 3 receiving farmyard manure treatment, and from plots 8, 9, 10 and 11 receiving P either singly or in combination, the element most deficient in the soil for proper microbial activity, than those in the grain from plots receiving other treatments. The yield of grain and the percentage composition of N and P in the grain were more in the case of the crop raised on farmyard manure treatment than those of the grain in the crop receiving complete minerals treatment, though in the latter these elements were applied in an available form. These observations showed that, when once the element deficient in the soil for proper microbial activity was supplied, enhanced microbial activity followed bringing into the soil more plant nutrients in an available form to the crop, and plants, in addition to their own powers of absorption, depend upon microbial activities for the supply of their nutrients.

TABLE IV

Permanent manurial series—Punjab Field, Pusa (A Series) crop barley 1943-44

Serial No.	Plot No.	Treatment	Yield per acre	Analysis on oven dry basis		Total in the grain		Increase over unmanured in total recoveries by grain	
				N	P_2O_5	N	P_2O_5	N	P_2O_5
			lb.	per cent	per cent	lb.	lb.	per cent	per cent
1	3	F.Y.M.	813·9	1·72	0·64	12·45	4·61	683·0	1407·0
2	6	$(NH_4)_2SO_4$	98·3	2·64	0·42	2·31	0·37	45·3	19·3
3	7	K_2SO_4	98·3	2·19	0·44	1·92	0·38	20·8	23·0
4	8	Super	402·6	1·67	0·80	6·01	2·85	278·0	800·0
5	9	K_2SO_4 and super	330·9	1 69	0·80	4·96	2·34	211·9	665·0
6	10	Ammonium sulphate, super and potassium sulphate.	295·2	1·6	0·45	4·2	2·79	164·1	812·8
7	11	$(NH_4)_2SO_4$ and super	697·8	1·67	0·46	10·4	2·8	554·1	817·5
8	13	Unmanured	80·4	2·2	0·42	1·59	0·31	..	..
9	14	$(NH_4)_2SO_4$ and K_2SO_4	62·6	2·79	0·48	1·55	0·26	—2·5	—13·8

Thus the results of the investigations so far carried out bear evidence to the correctness of the theory behind the method developed in this laboratory, and to the suitability of the method for judging the manurial requirements of the soil.

2. *Carbon-dioxide evolution studies as denoting the state of the soil regarding the content of available plant nutrients at the time of taking the soil sample.*

The following sets were set up with the April (summer), September (monsoon) 1941 and March (spring) 1942 soil samples of the plots 3A (F.Y.M.), 10A (N P K), 12A (G. M) and 16A (G.M. and Super) of the old permanent manurial series, Pusa.

1. Soil
2. Soil plus K
3. Soil plus P
4. Soil plus N
5. Soil plus N plus P
6. Soil plus N plus P plus K

The amounts of N, P or K added were the same as in the previous experiments.

The results obtained appear in Tables V, VI and VII.

TABLE V

Summer samples treatment in the laboratory	CO_2 evolved in mgm. per 100 gm. of soil				
	Check plot	N P K plot	G.M. plot	G.M. and super plot	F. Y. M.
Soil	46	64	44	65	66
Soil K	47	65	45	74	60
Soil P	59	53	56	68	77
Soil N	42	73	57	70	53
Soil N P.	59	73	54	69	63
Soil N P K	55	79	56	73	67

TABLE VI

Monsoon samples	CO_2 evolved in mgm. per 100 gm. of soil				
	13-A Check plot	10-A N P K plot	12-A G.M. plot	16-A G.M. and Super p ot	F.Y.M. plot
Soil	30	40	33	48	48
Soil K	34	41	37	48	41
Soil P	30	56	41	48	62
Soil N	21	36	29	58	42
Soil N P	32*	39	43	54	38
Soil N P K	36	37	37	53	43

*KP

TABLE VII

Spring samples	CO_2 evolved in mgm. per 100 gm. of soil				
	13-A Check plot	10-A N P K plot	12-A G.M. plot	16-A G.M. and Super plot	F.Y.M. plot
Soil	28	38	34	50·5	43
Soil K	34	34	37	46	44
Soil P	38	41	41	54	44
Soil N	29	44	34	57	41
Soil N P	36	51	47	61	48
Soil N P K	34	39	43	65	47

DISCUSSION.

Summer samples (N P K plot): The lack of response to P and K showed that these elements were not deficient in the soil. Response to N whenever added showed that the soil was rich in available carbon. This reflected the state of the plot as the plot received N P K additions before sowing the previous *rabi* crop and the high yield of that crop enriched the available carbon content in the soil.

Plot 12-A (*G.M.*): Carbon-dioxide evolution studies showed response to P. There was enough of organic matter in the soil, since the addition of N resulted in greater amount of carbon-dioxide evolved. N and P were used up by the previous crop. This was the actual state of affairs since this plot was green manured during *kharif* and no P was added at any time.

Plot 16-A (*G.M. and Super*): The larger quantity of crop that was produced in this plot took up large amounts of N, P and K. That the crop in this plot consumed more K than that in 12-A was indicated by response in carbon-dioxide evolution when K was added, while soil sample of 12-A did not show any such response. It may be seen that response to P was not so high in this plot as in 12-A. This was due to the fact that though P was used up by the growing plants in both the plots, 16-A received superphosphate at the time of green manuring while 12-A did not receive any phosphate.

Plot 3-A (*Farmyard Manure*): Depression due to N was taken to denote that the soil contained enough nitrogen.

Plots 12-A and 16-A: Depression due to N could not be taken to denote lack of organic matter, since large amount of carbon-dioxide was produced as compared to that evolved by check plot. Response to P showed that this element was used up by the crop.

Monsoon samples (Table VI): Plots 13-A and 10-A showed deficiency of organic matter as the response to nitrogen was in the negative. The control plot (13-A) was more depleted than the complete minerals because the organic remains from the crops were more in plot 10-A than in plot 13-A on account of higher yields in plot 10-A. These plots had not received any organic manure. So this was quite borne out by these responses. The positive response of 13-A to K, P, and N P K was also suggestive. The greatest response to N P K showed that practically all these became limiting factors in the make up of the fertility in this state. The greatest response to single treatment was shown by P and this indicated that P was the element most wanted and the depression by addition of K in P K treatment (over that of P) showed that the urgent need of the soil was not of K but of N in combination of P. Thus the indication of mineral manuring by N and P was clearly

shown. The negative response of plot 10-A to N P K, N and N P and the absence of response to K indicated that addition of these constituents were not necessary.

Spring samples (Table VII):

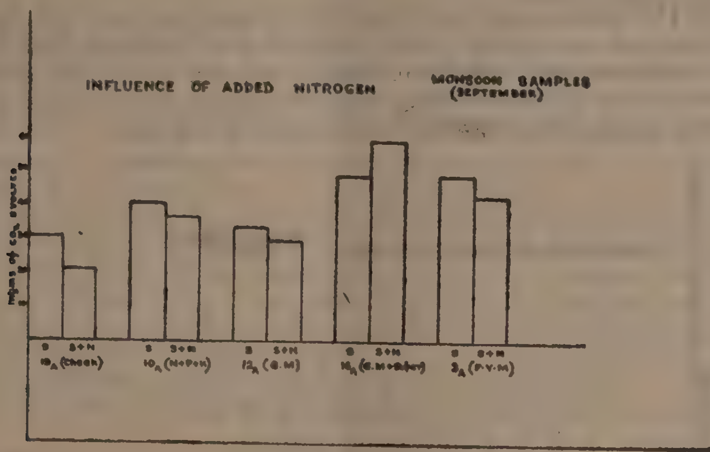

Fig. 1. CO_2 evolution studies Pusa soil

Studies with check plot soil sample 13-A (Check) showed that as a single element P was required. The amount of carbon-dioxide evolved in 10-A (N P K) samples denoted good level of fertility. It was indicated from these studies that N and P additions would raise its level of fertility.

Plot 12-A (*Green Manure*): Responses to the addition of N and P showed that these elements were consumed by the crop. As a single element P was most required.

Plot 16-A (*G.M. and Super*): The level of fertility was good as denoted by the large amount of carbon-dioxide evolved as compared with that evolved by check plot soil. Response to N showed the presence of large amount of organic matter in the soil.

Plot 3-A (*Farmyard Manure*): Since the soil sample from this plot evolved large amount of carbon-dioxide in comparison with that evolved by the check plot soil sample, it could be said that the soil was at a high level of fertility.

The effect of Nitrogen addition to the soil samples obtained in monsoon and spring Figures 1 and 2 denote the effect of nitrogen addition to the soil samples brought in September 1941 (monsoon) and in March (spring) 1942 respectively. When nitrogen was added to the monsoon samples from plots 13-A, 12-A and 3-A the amounts of carbon-dioxide evolved were much less than that evolved by soil alone. This depression due to addition of N was not observed in the case of the spring samples. Large amount of organic matter was decomposed rapidly during the months of July, August and September, the months following the operations of manuring the plots, and sowing the crop — due to the high microbial activity under the ideal conditions of moisture and temperature prevailing in these months — with the result that very little undecomposed organic matter was present at the time the samples were taken. When nitrogen was added the amount of available nitrogen was increased as compared to available carbon, resulting in less evolution of carbon-dioxide. This explained the depression to nitrogen addition in monsoon samples.

The decomposition of organic matter was relatively less in December, January and February, the period of low temperatures and less microbial activity. Hence more undecomposed organic matter was present in spring samples than in monsoon samples and as such no depression in amount of carbon-dioxide evolved was observed on adding nitrogen to these samples.

In green manure and super-treated plot, super was applied at the time of sowing the crop for green manuring in *kharif* and the green manure was ploughed under, in mid-*kharif*. So by the time

the samples were taken in monsoon the organic matter was not so rapidly mineralized as in other plots. Hence no depression due to addition of N was observed in monsoon soil samples of this plot as in others but on the other hand a response was obtained denoting that there was in the plot still easily decomposable organic matter.

Though in plot 12-A green manure was buried at the same time as in 16A, the green manure grown on this plot being very much less in quantity than that on the more fertile plot 16-A, decomposed more quickly than that grown and buried in 16-A and by the time the monsoon samples were taken much of the organic matter was mineralized. Hence the depression was observed in the amount of CO_2 evolved when nitrogen was added to the soil sample of this plot.

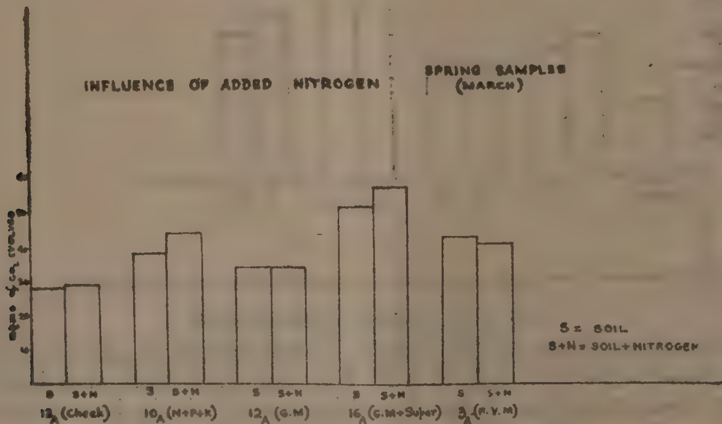

Fig. 2. CO_2 evolution studies Pusa soils

Thus these figures demonstrate how the depression or response in carbon-dioxide evolution to the addition of N could indicate the organic matter or nitrogen requirements of the soil.

Summary

Carbon-dioxide evolution studies with the plots of the permanent manurial series (Part I) showed that the order of the amounts of carbon-dioxide evolved in these plots was also the order of the crop yields. The different treatments given to these plots established differences in microbiological activity as reflected in carbon-dioxide evolution, simultaneously introducing differences in yields. This shows that conditions favourable for microbial growth and activity are also the conditions for proper plant growth, and proper microbial activity leads to high productivity of the soil.

In view of this, the possibility of the responses in rates of CO_2 evolution of the check plot soil sample to N, P or K additions either singly or in different combinations, reflecting the manurial need of a soil was examined. It was observed that the addition of P was essential to raise the fertility state of the Pusa soil, since P addition either singly or in combination greatly raised the amount of CO_2 evolved. N P combination was found to be quite beneficial, K addition singly or with P was shown to be of little value. The beneficial effect of adding organic manures was indicated. A similar conclusion was drawn from the manurial trials of the past 30 years. This investigation showed the possibility of suggesting the manurial needs of a soil from the responses in the amount of CO_2 evolved to the addition of N, P or K either singly or in different combinations to the soil sample.

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ROLE OF MICRO-ORGANISMS IN THE MAKE UP OF SOIL FERTILITY. III

CARBON-DIOXIDE EVOLUTION STUDIES AS A METHOD FOR DETERMINING MANURIAL NEEDS OF SOILS—STUDIES WITH DELHI SOIL

By S. V. Desai and W. V. B. Sundara Rao, Imperial Agricultural Research Institute, New Delhi.

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IN part II [Desai and Sundara Rao, 1944] studies with Pusa soil were described wherein it was shown that by determining the responses in the amount of carbon-dioxide evolved from the soil to the addition of N, P or K, the manurial needs of the soil can be judged. The indications were found to agree with those obtained from crop yields data at Pusa for the last 12 years. In the present investigation, studies were conducted with Delhi soil to examine whether this method could usefully be employed in determining the soil manurial requirements. The indications obtained from CO_2 evolution studies were compared with those obtained (*a*) from the crop yield data of pot-culture experiments and (*b*) from the available data of crop yields in the field trials (Joint experiments of Imperial Agricultural Chemist and Imperial Agriculturist). The N and P constituents in the crop were determined and this data and the available analytical data (N and P) of the crop in field trials were examined to study the effect of manuring on the total recoveries by the crop.

Experimental

The variations in the amount of carbon-dioxide evolved from Delhi soil with varying moisture content, but at constant temperature of 34°-C,. were determined. The optimum moisture level was found to be 18 per cent (½ the water-holding capacity).

The amounts of carbon-dioxide evolved from the soil with and without the addition of ammonium nitrate, super or potassium sulphate singly and in combination were studied, maintaining the soil moisture content throughout at 18 per cent and incubating the sets at 34°C. The experimental technique adopted was the same as that followed in studies with Pusa soil. In each case duplicate determinations were made and the mean was taken to represent the amount of carbon-dioxide evolved. A difference over 3 mgm. as in the earlier studies was considered to be significant. The data obtained were entered in Table I.

Table I

Amounts of carbon-dioxide evolved from the soil with and without different treatments

Serial No.	Treatment to the soil in the laboratory	Amount of carbon-dioxide evolved in mgm. per 100 gm. of soil in 10 days
		Mgm.
1	Soil alone	47
2	Soil + potassium sulphate	46
3	Soil + super	57
4	Soil + ammonium nitrate	56
5	Soil + ammonium nitrate + super	59
6	Soil + ammonium nitrate + super + potassium sulphate	57
7	Soil + potassium sulphate + super	44
8	Soil + potassium sulphate + ammonium nitrate	51

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From Table I it can be seen that responses were obtained to the addition of ammonium nitrate or super indicating that these two elements were deficient in Delhi soil. Wherever combinations included ammonium nitrate addition response was obtained in the amount of carbon-dioxide evolved. This denoted that of two elements nitrogen and phosphorus, nitrogen was more urgently needed. Further the response to nitrogen, in the light of the information obtained in connection with studies with Pusa soil (Part II of the paper) suggested that the soil contained enough of decomposable organic matter (carbon) and was deficient in available nitrogen, and as such better response in yields could be had to the addition of inorganic fertilizers which contain available nitrogen than to the addition of organic manures. The lack of response to the addition of potassium sulphate indicated that enough quantity of the element (potassium) was already present in the soil in available form.

Pot-culture experiments were conducted during *kharif* 1943, *rabi* 1943-44, and *kharif* 1944 to examine how these indications compare with those that can be had from yield data. In *kharif* 1943, the treatments were (*a*) unmanured, (*b*) ammonium nitrate, (*c*) super phosphate, (*d*) potassium sulphate, (*e*) ammonium nitrate and super phosphate, (*f*) ammonium nitrate and potassium sulphate, (*g*) potassium sulphate and super phosphate and (*h*) ammonium nitrate, super phosphate and potassium sulphate. In *rabi* 1943-44, as responses to the addition of potassium sulphate were almost *nil* during *kharif* 1943, the sets with treatments ammonium nitrate and potassium sulphate (NK), and potassium sulphate and super (KP) were dropped and sets with farmyard manure, farmyard manure +super, and farmyard manure+ super+ potassium sulphate were introduced to compare the effects of organic manures with those of the inorganic fertilizers. The residual effects of these treatments were studied in *kharif* 1944.

Details of procedure adopted in pot culture experiments : A composite soil sample 0-8 in. weighing about a thousand kilogrammes was obtained from an unmanured and uncultivated plot and sieved through one centimetre sieve. Glazed pots (24 in *kharif* 1943 and 27 in *rabi* 1943-44 and *kharif* 1944) 1 foot in height and 1 foot in diameter were selected. Washed gravel, 6 lb. in weight, was added at the bottom of each of the pots ; 50 lb. portions of soil were weighed out and kept in separate heaps.

The following stock solutions were prepared :

1. 160·5 gm. of ammonium nitrate were dissolved in 1 litre of water; 20 cc. of this solution were added to each of the pots receiving nitrogen treatment in the manner detailed below, so that the amount of nitrogen added was at the rate of 5 mgm. per 100 gm. of soil, equivalent to 100 lb. of nitrogen per acre.

2. 125 gm. of potassium sulphate were dissolved in 1 litre of water so that by adding 20 cc. of this solution per pot of 50 lb. soil, 5 mgm. of K_2O were supplied to every 100 gm. of soil. This is equivalent to 100 lb. K_2O per acre.

In pots receiving super phosphate, 6·4 gm. of super per pot were added as detailed below so that 10 mgm. of P_2O_5 were supplied to every 100 gm. of soil which corresponds to 200 lb. P_2O_5 per acre.

Addition of fertilizers : In cases where ammonium nitrate or potassium sulphate was added a small handful of the soil was taken in a basin and the requisite quantity of the mineral solution was added to it. The soil was intimately mixed and a further handful of soil was added and again mixed. This material was then intimately mixed with the main portion of the soil lying on the floor.

In cases where super phosphate was added the requisite quantity was weighed out and transferred to handful of the soil. The soil was then intimately mixed. Another handful of the soil was then added and again mixed. This material was scattered uniformly over the main portion of dry soil lying on the floor and the mixture of the whole completed.

The order of mixing was three pots unmanured, three pots ammonium nitrate, three pots potassium sulphate, three pots super, three pots ammonium nitrate and super, three pots super and potassium sulphate, three pots ammonium nitrate and potassium sulpate and three pots ammonium nitrate, super and potassium sulphate. This order was maintained to avoid contamination from the complete fertilizer series. For the same reason the hands were washed between each set of replicates.

Filling up the pots : A measured quantity of water was added from the mouth piece of the wash bottle. After adding some water the soil was turned over and any damp lumps were broken down by hand. Further portions of the water were then added with alternate working by hand until the whole quatity was uniformly mixed with the soil. The aim was to introduce a quantity of water which would damp the earth without, however, making it so damp that the clay could be 'puddled' when the jar was filled, [Leather, 1907]. The damped earth was then filled into the jar and as each handful was introduced, it was levelled and pressed in with clenched fist quite firmly up to a height of 6 in., while the soil at the top (0-3 in.) was allowed to remain more loose. The pots were arranged on the bench so that replicates were not adjacent. Shadow effects were eliminated by a regular inter-change of the pots in a series throughout the season.

A pint of water was added in each pot on the first day. On the second day the surface soil was levelled and 25 small holes on the surface of the soil per pot were made. In *kharif* 1943, *jowar* seeds were placed one in each hole, pressed into the soil with the finger and then covered. Shoots appeared on the third day from the date of sowing. When the plants were a little grown, 20 plants were kept in each pot and the rest were removed so as to have the same number throughout in each of the pots. Watering of the pots was done on every second day during the early stages of growth and on every day during the later stages. Watering was discontinued entirely for four days previous to harvesting. Among the pots receiving single treatments, super-treated pots showed best growth in early stages. Later ammonium nitrate-treated pots showed the best growth, super-treated pots becoming slightly pale in colour. The crop was harvested after growing for two months. The green weights and dry weights of the fodder were recorded. Nitrogen and phosphorus contents in the crop were determined and expressed as percentage values on dry basis. Nitrogen was determined according to the methods recommended in 'Methods of Analysis—A. O. A. C.' (1940) and phosphoric acid by the method of Fiske and Subbarao [1925] which was tested in this laboratory by comparing with standard methods and was found to be quite reliable as a rapid method. Table II shows the yields, the nitrogen and phosphoric acid contents (total amounts removed by crops) of the crop and the percentage increase in these values over those of the crop from the unmanured pots. The yields given under each treatment were the mean values of three pots.

TABLE II

Pot culture experiments—kharif *1943. Crop*—jowar *fodder*

Treatment	Yield of fodder dry	P_2O_5 and N in the crop		Total amounts in the crop		Increase over the unmanured	
		P_2O_5	N	P_2O_5	N	P	N
	gm.	per cent	per cent	gm.	gm.	per cent	per cent
Unmanured	24·3	0·47	0·83	0·11	0·20	..	..
Ammonium nitrate	35·7	0·57	1·22	0·20	0·44	78·20	117·50
Super phosphate	30·3	0·69	0·71	0·21	0·22	83·00	7·53
Potassium sulphate	22·7	0·46	0·62	0·10	0·14	—6·80	—30·50
Ammonium nitrate + super	42·7	0·58	1·09	0·24	0·46	111·90	131·30
Ammonium nitrate + sulphate of potash	37·3	0·37	1·12	0·14	0·42	20·84	107·20
Sulphate of potash + super	25·7	0·49	0·54	0·13	0·14	10·33	—31·00
Ammonium nitrate + super + sulphate of potash	38·0	0·57	1·10	0·22	0·38	89·70	90·80

N.B.—All the figures were expressed correct to second decimal place, though the calculations were made on values correct to fourth decimal place.

Table III

Pot culture experiments 1943-44 rabi. *Crop wheat*

Serial No.	Treatment	Yield		Analysis on oven dry basis				Total P_2O_5 in crop			Total nitrogen in the crop			Increase over unmanured in total content	
				P_2O_5		N									
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Total	Grain	Straw	Total	P_2O_5	N
		gm.	gm.	per cent	per cent	per cent	per cent	gm.	gm.	gm.	gm.	gm.	gm.	per cent	per cent
1	Unmanured	19·4	28·6	0·81	0·09	1·93	0·26	0·14	0·02	0·16	0·34	0·07	0·41	..	..
2	Ammonium nitrate	24·8	35·2	0·67	0·17	2·94	0·44	0·15	0·05	0·20	0·65	0·16	0·81	22·1	107·1
3	Super phosphate	20·7	34·3	0·86	0·22	1·82	0·33	0·16	0·07	0·23	0·33	0·1	0·43	38·0	10·0
4	Potassium sulphate	12·8	23·2	0·88	0·10	1·92	0·27	0·10	0·02	0·12	0·21	0·06	0·27	—27·0	—31·6
5	Ammonium nitrate + super	38·2	52·8	0·89	0·10	2·58	0·60	0·30	0·05	0·35	0·87	0·28	1·15	113·5	193·6
6	Ammonium nitrate + super + potassium sulphate	33·5	47·5	0·85	0·08	2·24	0·47	0·25	0·04	0·29	0·66	0·20	0·86	77·3	121·4
7	Farmyard manure	15·3	24·7	0·83	0·17	1·65	0·29	0·10	0·04	0·14	0·23	0·06	0·29	—18·4	—24·5
8	Farmyard manure + super	15·8	26·2	0·88	0·22	2·04	0·36	0·13	0·05	0·18	0·30	0·08	0·38	12·3	—10·2
9	Farmyard manure + super + potassium sulphate	10·7	21·3	0·96	0·18	1·82	0·25	0·10	0·02	0·13	0·18	0·07	0·22	—20·9	—37·0

N.B.—All the figures were expressed correct to second decimal place for easy reference, though all the calculations were based on values correct to fourth decimal place.
Critical difference at 5 per cent level for wheat grain yields = 3·91.
Critical difference at 5 per cent level for wheat strawyields = 4·69.

1943-44 **rabi** *crop :*

In this season the soil in the pots was removed and fresh soil was put in. The crop sown was wheat. The same details regarding experimental technique as in the previous cases were followed. Farmyard manure addition was included in this season among the treatments and the treatments were as under with three pots in each case.

Treatments : (1) Unmanured, (2) ammonium nitrate, (3) super phosphate, (4) potassium sulphate, (5) ammonium nitrate and super phosphate, (6) ammonium nitrate, super phosphate and potassium sulphate, (7) farmyard manure, (8) farmyard manure + super and (9) farmyard manure, super and potassium sulphate.

Farmyard manure was applied at the rate of 5 mgm. of nitrogen per 100 gm. of soil, a month before sowing. The crop was harvested after growing it to maturity, yields of grain and straw were recorded and the percentage composition of N and P_2O_5 in both grain and straw were determined. Table III shows the yield of grain and straw, N and P_2O_5 contents (total amounts) in the crop and the percentage increase in the content of these in the crop from differently treated pots over that of the crop from the unmanured pots.

Kharif *1944 :*

In this season the residual effects of the fertilizers on the yields of *Jowar* fodder were studied. The crop was harvested after growing for two months. The green and dry weights of the fodder were recorded and the N and P_2O_5 contents in the crop were determined. The dry weights, percentage composition of N and P_2O_5 in the crop, total contents of these in the crop and the percentage increase over check are presented in Table IV.

The determination of K in the crop was omitted because this element is not deficient in Indian soils in general and in Delhi soil in particular.

TABLE IV

Pot culture experiments—kharif *1944.* (*Residual effects*). *Crop* Jowar *fodder*

Serial No.	Treatment	Yield of fodder (dry)	P_2O_5 and N in the crop		Total amounts in the crop		Increase over the unmanured in total amounts of	
			P_2O_5	N	P_2O_5	N	P_2O_5	N
		gm.	per cent	per cent	gm.	gm.	per cent	per cent
1	Unmanured . . .	17·0	0·22	0·84	0·038	0·143	..	..
2	Ammonium nitrate . .	25·0	0·22	1·01	0·056	0·2535	46·95	77·60
3	Super phosphate . .	24·3	0·33	0·81	0·080	0·197	111·66	37·70
4	Potassium sulphate . .	19·3	0·24	0·44	0·047	0·084	23·53	—41·30
5	Ammonium nitrate + super	27·0	0·33	0·58	0·089	0·159	105·30	10·90
6	Ammonium nitrate + super + potassium sulphate	22·0	0·34	0·59	0·074	0·129	95·94	—9·50
7	Farmyard manure . .	17·0	0·29	0·62	0·050	0·106	31·30	—26·10
8	Farmyard manure + super .	30·0	0·39	0·55	0·115	0·166	216·11	16·29
9	Farmyard manure + super + potassium sulphate	27·0	0·27	0·50	0·074	0·135	96·03	—5·50

N.B.—Critical difference at 5 per cent level for *jowar* fodder yield = ±3·74.

DISCUSSION

In this investigation comparison was made between the manurial needs of the soil as were indicated from carbon dioxide evolution studies with those inferred from the yield data of the crop in the pot culture experiments. Further it was examined, whether the addition of the mineral most deficient for proper microbial activity in the soil has actually led to an increase in the mineral supplied and other minerals as well in the crop in order to see how far this theory of the effect of beneficial manuring developed in this laboratory was in conformity with the data obtained in studies with Delhi soil.

The amounts of carbon-dioxide evolved from the soil with and without the addition of fertilizers in the laboratory and the yields for *kharif* 1943 were entered in Table V, while the yields for *rabi* 1943-44 and for *kharif* 1944 were entered in Table VI.

From these Tables it can be seen that the addition of N, P, NP, NK or NPK to the soil in the laboratory evolved definitely larger amounts of carbon-dioxide from the soil as compared with the amounts evolved from the untreated soil, and these minerals when added to the soil in these combinations in pot culture experiments raised the crop-producing capacity of the soil as was judged from the yield data. Wherever. N was added (either singly or in combination) better yields were obtained indicating that of the two elements N and P, N was more deficient in the soil. This was in agreement with the observation from carbon-dioxide evolution studies wherein definite responses in the amounts of carbon-dioxide evolved were observed in all cases where N was added. Though the addition of super to the soil in the laboratory led to an increase in the amount of carbon-dioxide evolved, to the same extent as the addition of nitrogen did, the increase in yield was not the same as in the case when nitrogen was added. This was due to the fact that the major need of the soil was nitrogen. When super was added, increased microbial activity led to increased synthesis of mineral nutrients including nitrogen, from the decomposition of soil organic matter. But as nitrogen so supplied in available form was taken up by the growing crop, in later stages of growth the available nitrogen content in the soil, which was already very low as compared to available carbon content in the humus was lowered leading to less microbial activity. As such, the final crop yields in super treated pots were low as compared to those of ammonium nitrate-treated pots. This appeared to be the reason why the growth in super-treated pots was much better in the early stages of growth than in later stages. In the ammonium nitrate-treated pots, since the major need of the scil (nitrogen) was supplied, microbial activity was enhanced and the essential plant nutrients were released in an available form leading to better crop yields. In the later stages of crop growth, the P content in soil was lowered but the adverse effect on microbial activity due to lowering of available P content in the soil was not to the same extent as in the case when the content of the available nitrogen was lowered. Potassium sulphate addition depressed the crop yield as compared to the yield of the crop from the unmanured pots. When potassium sulphate was added along with ammonium nitrate or with super, or with ammonium nitrate and super, the yields were low as compared to those with the addition of ammonium nitrate, super, or ammonium nitrate and super respectively. This was also in conformity with the indications from carbon-dioxide evolution studies wherein depression in the amount of carbon-dioxide evolved from the soil was observed whenever potassium sulphate was added.

TABLE V

Carbon-dioxide evolution and crop yields—responses to fertilizer additions

Serial No.	Treatment	CO_2 evolved in mgm. per 100 gm. soil in 10 days	*Kharif* 1943-*jowar* crop	
			Yield of fodder (dry weights) gm.	Increase over unmanured per cent
1	Unmanured	47	24·3	..
2	Ammonium nitrate	56	35·7	46·9
3	Super	57	30·3	24·7
4	Potassium sulpate	46	22·7	—6·6
5	Ammonium nitrate and super	59	42·7	75·7
6	Ammonium nitrate and potassium sulphate	51	37·3	53·5
7	Potassium sulphate and super	44	25·7	5·8
8	Ammonium nitrate, super and potassium sulphate	57	38·0	56·4

Critical difference at 5 per cent level for *jowar* fodder yield=±7·34.

TABLE VI

Carbon-dioxide evolution and crop yields—responses to fertilizer additions

Serial No.	Treatment	CO_2 in mgm. evolved from 100 gm. soil	*Rabi* 1943-44 wheat		*Kharif* 1944 (residual effects) crop *jowar*	
			Yield (grain + straw) gm.	Per cent increase over unmanured	Yield of fodder (dry weight gm.)	Per cent increase over unmanured
1	Unmanured	47	48	..	17	..
2	Ammonium nitrate . . .	56	60	25	25	47·05
3	Super	57	55	14·6	24·3	42·94
4	Potassium sulphate	46	36	—25·0	19·3	13·53
5	Ammonium nitrate + super . .	59	91	89·6	27·0	58·83
6	Ammonium nitrate + super + potassium sulphate	57	81	68·8	22·0	29·42
7	Farmyard manure	..	38	—35·4	17·0	..
8	Farmyard manure + super . .	..	42	—12·5	30·0	76·47
9	Farmyard manure + super + potassium sulphate	..	32	—33·3	27·0	58·83

In rabi 1943-44 the yield of the crop receiving farmyard manure was definitely lower than that of the crop in the NPK treated pots and also that of the crop from unmanured pots. This failure of response to organic manures was indicated from carbon-dioxide evolution studies wherein definite response to nitrogen (Table I) suggested that the immediate need of the soil was the raising of available nitrogen content and as such response could be had to the additional inorganic fertilizers, but not to organic manures which would further raise the carbon content. It was observed, in the case of Pusa soil, that the direct manurial effects of organic manures were superior to those of inorganic fertilizers and this was borne out from carbon-dioxide evolution studies wherein slight depression or definite lack of response to the additional nitrogen was obtained, indicating that the available carbon content in the soil humus was low and as such definite response in yields can be had only when the manuring included the addition of carbon, i.e. when organic manures were supplied. Thus the response or depression in the amount of carbon-dioxide evolved from the soil to the addition of nitrogen appears to indicate the response of the soil to inorganic fertilizers or organic manures. While several methods were developed for determining the mineral deficiencies in the soil, there is yet no reliable laboratory method by which the response of soil to inorganic fertilizers or organic manures can be judged. The proposed method appears to serve this purpose as its indications agreed with those inferred from the yield data in the case of the soils from Pusa and Delhi.

Further it is interesting to note that by chemical analysis these indications were not obtained since in both Delhi and Pusa soils the amount of total carbon and total nitrogen were almost the same, as can be seen from Table VII.

The other indications of manurial needs observed in this season were the same as were noticed in *kharif* and were in agreement with the inferences drawn from carbon-dioxide evolution studies.

TABLE VII

Composition of Delhi and Pusa soils

Soil	Carbon	Nitrogen	P_2O_5		K_2O	
			Total	Available	Total	Available
	per cent	per cent	per cent	per cent	per cent	per cent
Delhi soil	0·408	0·03	0·089	0·030	0·578	0·067
Pusa soil	0·41	0·03	0·100	0·00045	0·640	0·0035

In 1944 *kharif* the residual effects were studied. Better responses were obtained when nitrogen was added either singly or in combination or when P was added. NP addition showed best results indicating that both the elements were deficient in the soil. Residual effect or farmyard manure alone was slightly better than the direct effect observed in the previous *rabi* but still the yield was less than that from the complete minerals treated pots and equal to that obtained from the unmanured pots. Farmyard manure + super, and farmyard manure + super + potassium sulphate addition showed definite responses in the residual effects, since the addition of super in available form, one of the elements deficient in the soil for proper microbial activity, enhanced the rate of decomposition of added organic matter and by the time the residual effects were studied, mineral nutrients were released from the added organic matter in available form as a result of this enhanced microbias activity.

Mineral recoveries by the crop : From Table II showing the yields, percentage and total contents of N and P in the *kharif* crop [1943], and the percentage increases over control in the content (total amount) of these minerals, it can be seen that by applying nitrogen in the form of ammonium nitrate a larger amount of phosphorus was removed into the crop than that in the crop from the unmanured pots, showing that when, once the mineral deficient in the soil for proper microbial activity was supplied, the content of this element and other elements as well, in the crop would increase as a result of a greater availability of these in the soil due to enhanced microbial activity. The percentage increase over control in the P content of the crop from the pots receiving N treatment was more than the percentage increase over check (last 2 columns in Table II) in N content in the crop receiving P treatment. This showed that the soil was deficient more in nitrogen than in phosphorus. The addition of potassium sulphate either singly or in combination did not raise the P and N contents (percentage or total) in the crop over control, but on the other hand lowered indicating that the soil was not in need of this mineral. These indications were identical with the inferences drawn from carbon-dioxide evolution studies.

Similar results were obtained in *rabi* 1943-44. From Table III, it is clear that more P was taken up by the crop from the ammonium nitrate treated pots and more N was taken up from the super treated pots as compared to these intakes in the crop from the unmanured pots, which showed that these two elements were deficient in the soil.

The total nitrogen and phosphorus contents in the crop from the farmyard manure treated pots were definitely lower than when the inorganic fertilizers were supplied. Even the percentage amount of these were in general lower in the farmyard manure treated pots as compared to those in crop receiving NPK treatment (Table III). The addition of farmyard manure raised the available carbon content in the soil humus, which was already high and lowered the proportion of nitrogen content which was already low for proper microbial activity and as such the crop could not obtain the necessary nutrients.

Thus the indications of the manurial requirements of Delhi soil from carbon-dioxide evolution studies agreed closely with those inferred from the yield data and the analysis of the data relating to N and P contents in *jowar* and wheat crops receiving different manurial treatments in pot culture trials. It was also observed from the analysis of the crop, that the result of beneficial manuring by supplying the deficient mineral in the soil was, the supply of the element added and other elements in an available form to the plant.

TABLE VIII

Responses in carbon-dioxide evolution in the soil sample to the addition of N, P and K in the laboratory, and the percentage increases over check, of N and P in the crops in kharif *and* rabi, *in pot culture experiments*

Serial No.	Treatment in the laboratory	Co_2 evolved in mgm. per 100 gm. of soil	Percentage increase over check, in N and P contents of the crop			
			kharif (1943)		*rabi* 1943-44	
			P	N	P	N
1	Soil alone	47	..	..	..	..
2	Soil + N (ammonium nitrate)	56	78	118	22	107
3	Soil + P (super)	57	83	8	38	10
4	Soil + K (potassium sulphate)	46	—7	—31	—27	—32
5	Soil + N + P	59	112	131	114	194
6	Soil + N + K	51	21	107	..	..
7	Soil + K + P	44	10	—31	..	..
8	Soil + N + P+K	57	90	91	77	121
9	Soil + F.Y.M.	..	..	..	—18	—25
10	Soil + F.Y.M. + P	..	..	..	—12	—10
11	Soil + F.Y.M. + P.K.	..	..	..	—21	—37

The residual effects of farmyard manure and super treatment observed in *kharif* 1944 (Table IX) were definitely better than the direct manurial effects observed in *rabi* 1943-44 as can be seen from percentage increases in recoveries. By the time the residual effects were studied, due to the supply of phosphorus, one of the elements deficient in the soil for proper microbial activity, a large portion of the farmyard manure added was decomposed and as such the crop could obtain relatively larger amounts of nutrients than in *rabi*

The addition of potassium sulphate either to farmyard manure and super treatment or to ammonium nitrate and super treatment reduced the recoveries of both nitrogen and phosphorus, showing that the supply of this mineral was not necessary but even may prove harmful in these combinations.

While organic manures have decidedly beneficial effect of increasing crop yields due to increase in carbon-dioxide content in the atmosphere among other reasons, in Delhi soil their direct effects were low, because they increased the available carbon content in the soil which was already high as compared to available nitrogen content for proper microbial activity, as noticed by response in the amount of carbon-dioxide evolved from Delhi soil to the addition of nitrogen and reduced, on addition to the soil, the rate of microbial activity. As such the synthesis of available plant nutrients had not proceeded rapidly enough, Even in the residual effects response could be had only when super was supplemented to farmyard manure treatment.

TABLE IX

Pot culture experiments—direct and residual effects (1943-44)

Treatment	Yield			Nitrogen			Phosphorus (P_2O_5)		
	Direct effect Wheat grain + straw gm.	Residual effect *Jowar* fodder gm.	Total	Direct effect	Residual effect	Total	Direct effect	Residual effect	Total
Unmanured	48	17	65	0·41	0·143	0·553	0·16	0·038	0·198
Ammonium nitrate	60	25	85	0·81	0·254	1·064	0·20	0·056	0·256
Super	55	24	79	0·43	0·197	0·627	0·23	0·080	0·310
Potassium sulphate	36	19	55	0·27	0·084	0·354	0·12	0·047	0·167
Ammonium nitrate + super	91	27	118	1·15	0·159	1·309	0·35	0·089	0·439
Ammonium nitrate+ super + potassium sulphate	81	22	103	0·86	0·129	0·989	0·29	0·074	0·364
F.Y.M.	36	17	55	0·29	0·106	0·396	0·14	0·050	0·190
F.Y.M. + super	42	30	72	0·38	0·166	0·546	0·18	0·115	0·295
F.Y.M. + super + Potassium sulphate.	32	27	59	0·27	0·135	0·405	0·13	0·074	0·204

Co_2 evolution studies on soil samples from field experiments : Next an attempt was made to examine whether any correlation existed between soil microbial activity and crop yields in plot experiments of the Imperial Agriculturist and the Imperial Agricultural Chemist in progress at the Imperial Agricultural Research Institute, New Delhi. Soil samples were obtained from plots from block 1 receiving different forms of nitrogenous manures and fertilizers, and the amount of carbon-dioxide evolved from 100 gm. of the soil from each plot in a period of 10 days was determined. The experimental technique followed was the same as in previous cases. In Table X were presented the amounts of carbon-dioxide evolved from the soil samples taken from the plots receiving different treatments and the yields of the corresponding plots. It is clear from this Table that in general high yields in the plots were associated with high amounts of carbon-dioxide evolved from the soil samples and low yields of the plots with low amounts of carbon-dioxide evolved from the soil samples from the corresponding plots. The plots in which the soil samples evolved 56 mgm. or more of carbon-dioxide per 100 gm. of soil gave yields which were 210 lb. (230$\pm$20) or more of green fodder. The plots from which the soil samples evolved 52 mgm. or less of carbon-dioxide gave yields below 200 lb. (175 $\pm$ 25). From the results of these plot experiments and those of other experiments of the Imperial Agriculturist, which were recorded in Tables XI, XII and XIII, it can be seen that the complete minerals treated plot gave better yields than the plots receiving farmyard manure. But when half the nitrogen was supplied in the form of artificials and helf in the form of organic manures the yields were in between two limits (between yields of artificials and those of organics). This definitely pointed to the deficiency of available nitrogen in the soil.

The recoveries of nitrogen by the crop in the different plots were calculated and from this data, presented in Table XIV it can be seen that large amount of nitrogen was present in the crop from the plot receiving artificial fertilizers than from the plots receiving organic manures only.

TABLE X

Delhi plot experiments—carbon-dioxide evolution and crop yields. (Yield data were supplied through the courtesy of the Imperial Agriculturist.)

Plot	Treatment	CO_2 evolved in mgm. per 100 gm. of soil in 10 days	Mean yields in *kharif* 1942, crop maize in two plots and *sorghum* in two plots per treatment (lb.)
10 D	Rape cake at 20 lb. nitrogen per acre	66	210
1 C	Activated sludge at 20 lb. N per acre	63	240
8 L	N at 20 lb. in the form of ammonium sulphate + super at 20 lb. $P_2O_5+K_2SO_4$ at 20 lb. K_2O per acre	59	250
9 H	Compost at 20 lb. N per acre	56	220
2 F	Activated sludge at 20 lb. N + super 20 lb. $P_2O_5+K_2SO_4$ at 20 lb. K_2O per acre	59	250
3 E	Farmyard manure at 20 lb. N + super at 20 lb. $P_2O_5+K_2SO_4$ at 20 lb. K_2O per acre.	51	190
5 G	Rape cake at 20 lb. N + super at 20 lb. $P_2O_5+K_2SO_4$ at 20 lb. K_2O per acre	51	200
11 J	Farmyard manure at 10 lb. N + ammonium sulphate at 10 lb. N + super at 20 lb. $P_2O_5+K_2SO_4$ at 20 lb. K_2O per acre	42	200
12 A	Check	42	150
4 B	Farmyard manure at 20 lb. N per acre	42	180
	Coefficient of correlation	..	+0·89

TABLE XI

Delhi plot experiment yields—replications 6. (Yield data were supplied through the courtesy of the Imperial Agriculturist.)

Treatment	Yields per acre in lb.				
	1941 *kharif jowar* fodder	1941-42 *rabi* wheat crop		1942 *kharif* maize + *sorghum* fodder	1942-43 *rabi* wheat grain
		Grain	Straw		
Unmanured	6937·6	173·6	435·0	2980·0	210·6
NPK at 20 lb. N per acre	7913·4	274·5	775·0	5005·0	287·6
F.Y.M. at 20 lb. N per acre	7130·0	200·4	498·4	3675·0	217·2
F.Y.M. at 10 lb. N + ammonium sulphate at 10 lb. N + super at 20 lb. P_2O_5 + potassium sulphate at 20 lb. per acre	7800·0	245·6	..	4000·0	..

In Tables X and XI the amounts of super + K_2SO_4 when added with organics were used in quantities to make up the total P_2O_5 and K_2O equal to 20 lb. per acre in each case.

Next the analytical data obtained by the senior author, Messrs Sirajuddin, Maqsood Ali and Subbiah were examined to see whether the effect of fertilizers on the crop composition in their experiments will be similar to those observed in the authors' pot culture experiments.

TABLE XII

Russell's Experimental Plots, Delhi—Replications 6

Recoveries of N by the crop as percentage increase over check

(Data of the senior author, Sirajuddin, Maqsood Ali, and Subbiah)

Serial No.	Treatment	1941 *kharif* *jowar* fodder	1941-42 *rabi* wheat grain straw	1942 *kharif* maize fodder	1942 *kharif* *jowar* fodder
1	F. Y. M. at 20 lb. N per acre	—6·48	5·11	29·75	22·8
2	Activated sludge at 20 lb. N per acre	7·18	21·0	47·23	88·59
3	Rape cake at 20 lb N per acre	11·62	31·48	25·13	57·65
4	F. Y. M. at 20 lb. N + super at 20 lb. P_2O_5+K_2SO_4 at 20 lb. K_2O per acre	5·62	23·57	22·44	25·19
5	Activated sludge at 20 lb. N + super at 20 lb. P_2O_5+ K_2SO_4 at 20 lb. K_2O per acre	17·18	4·65	39·77	72·14
6	Rape cake at 20 lb. N + (super) at 20 lb. P_2O_5+ K_2SO_4 at 20 lb. K_2O per acre	21·31	22·72	20·66	55·49
7	Compost at 20 lb. N per acre	—15·07	18·4	35·16	38·98
8	Compost at 10 lb. N + ammonium sulphate at 10 lb. N + super at 20 lb. P_2O_5 per acre	15·47	16·81	26·5	38·3
9	J. F. Y. M. at 10 lb. N + ammonium sulphate at 10 lbs. N + super at 20 lb. P_2O_5 per acre	22·59	24·57	7·59	79·2
10	Ammonium sulphate at 20 lb. N + super at 20 lb. P_2O_5+K_2SO_4 at 20 lb. K_2O per acre	20·66	33·32	53·45	75·32

TABLE XIII

Mean nitrogen recoveries—(Calculated from Table XII)

Serial No.	Treatment	Percentage increase of N intake over check (mean for all the crops)
1	F. Y. M. at 20 lb. N per acre	13
2	Activated sludge at 20 lb. N per acre	41
3	Rape cake at 20 lb. N per acre	32
4	F. Y. M. at 20 lb. N + super at 20 lb. P_2O_5+K_2SO_4 at 20 lb. K_2O per acre	19
5	Activated sludge at 20 lb. N + super at 20 lb. P_2O_5 + K_2SO_4 at 20 lb. K_2O per acre	33
6	Rape cake at 20 lb. N + super at 20 lb. P_2O_5+K_2SO_4 at 20 lb. K_2O per acre	30
7	Compost at 20 lb. N per acre	19
8	Compost at 10 N + ammonium sulphate at 10 lb. N + super at 20 lb. P_2O_5 per acre	36
9	F. Y. M. at 10 N + ammunium sulphate at 10 lb. N + super at 20 lb. P_2O_5 per acre	36
10	Complete minerals (N+P+K) (Ammonium sulphate at 20 lb. N+Super at 20 lb. P_2O_5+K_2SO_4 at 20 lb. K_2O per acre)	46

Among combination of artificials and organic manures, only those where inorganic nitrogen was added showed significantly increased recoveries. In Table XIII the mean percentage increase for all the crops in nitrogen recoveries over the check in the different treated plots at Delhi, were entered. It can be seen from this Table that maximum amount of N was recovered in the crop from the complete minerals treated plot. Next are in the order of recoveries, the crop from the plot receiving activated sludge and then the crops from the plots receiving organic manures along with inorganic fertilizers. The next position was occupied by the crop raised on rape cake manuring. In the case of the crops in farmyard manure and compost-treated plots, the percentage increase of N over check was below 20. These results showed that in general better response was obtained when the fertilizer was in inorganic form or when the manure included the addition of inorganic nitrogen to organic manures. Responses to complete organic manures in nitrogen intake was much lower than that by inorganic fertilizers. In Table XIV were entered the percentage increases over control in the recoveries of P_2O_5 in the complete minerals treated plot, in the plot receiving farmyard manure and in the plot receiving artificials and farmyard manure. From this Table it can be seen (1) that the crop receiving organic manures showed a percentage increase in P_2O_5 recovery over check which was less than that obtained from the crop receiving complete minerals treatment, (2) the percentage increase over check in P_2O_5 recovery by the crop when super phosphate was supplied along with nitrogen, half in inorganic and half in organic form, was greater than that recovered by the crop when super was added along with nitrogen in organic form only. In the former case the recovery was almost equal to that from the complete minerals treated plot. These field results clearly denoted that the nitrogen in available form was deficient in the soil and when once this element was supplied more nitrogen and other minerals like phosphorus were likely to be brought into an available form to the crop.

TABLE XIV *

Field trials—Recoveries of P_2O_5 by wheat crop (1941-42)

Serial No.	Treatment	Total P_2O_5 in the crop lb.	Percentage increase over check (unmanured)
1	Unmanured	0·09778	..
2	Ammonium sulphate at 20 lb. N + super at 20 lb. P_2O_5+potassium sulphate at 20 lb. K_2O per acre	0·16305	66·8
3	F. Y. M. at 20 lb. N per acre	0·10838	10·84
4	F. Y. M. at 10 lb. N + ammonium sulphate at 10 lb. N + super at 20 lb. P_2O_5+K_2SO_4 at 20 lb. K_2O per acre	0·16205	65·15
5	F. Y. M. at 20 lb. N + super at 20 lb. P_2O_5+K_2SO_4 at 20 lb. K_2O per acre	0·13912	42·23

* Data of the senior author, Sirajuddin, Maqsood Ali and Subbiah.

Thus the data obtained in field trials were in agreement with the results obtained in pot culture experiments and showed that the response in yields and in mineral intake was better when the soil was supplied with inorganic fertilizers, than when organic manures were applied. This observation was in conformity with the indications from carbon-dioxide evolution studies, namely, the need of the soil was the supply of nitrogen in inorganic form.

Thus investigations with Delhi and Pusa soils indicated that the nitrogen, phosphorus and potassium needs of the soil or the beneficial effects of inorganic or organic manuring may probably be judged from the responses in the amounts of carbon-dioxide evolved from the soil sample to the addition of N, P or K.

Summary

(1) The suitability of the method of determining the manurial requirements of the soil from the responses in CO_2 evolution from the unmanured soil samples to the addition of the different fertilizers was examined, with respect to Delhi soil. The indications obtained by this method were the same as those got from the yield data of wheat and *jowar* crops in the pot culture experiments. Further it was found possible to obtain indications as to whether a soil responds to organic manures or inorganic fertilizers. The available data of the field trials confirmed the laboratory observations.

(2) From carbon-dioxide evolution studies it was observed that nitrogen was the element most deficient in the soil for microbial activity and its addition to this soil increased the nitrogen as well as the phosphorus content in the crop. This suggested that by supplying the deficient element for proper microbial activity, microbial activity in the soil was enhanced and as a result, a large quantity of minerals was brought into available forms from the relatively unavailable state. Thus the effect of manuring seems to be more indirect than direct on the crop and is by way of changing the relation of the soil to the crop with respect to the available mineral content.

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CAPILLARY RISE OF MOISTURE IN SOIL COLUMNS

By A. G. Asghar and C. L. Dhawan, Irrigation Research, Punjab, Lahore

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(With five text figures)

WHEN a vertical soil column is left in contact with free water at the bottom the moisture rises upwards in the soil column up to a certain height and is retained by the soil against the gravitational forces. This is termed 'the capillary moisture'. Briggs [1897] conceived that moisture exists in the form of films around the soil particles and the forces arising from the curvature of these moisture films were the cause of retention of water. The height up to which the moisture could thus rise from the free water surface contains a continuous and tightly stretched film throughout the soil medium. The water films around the particles nearer the free water surface are thicker than the films around the particles at a higher altitude and the movement of capillary moisture takes place from thicker to the thinner films. As the curvatures of films depend upon the size of the particles, the forces developed in finer particles are higher than in the coarser particles and hence moisture would rise to a greater height in finer soils.

Considering a soil column made of a number of soil particles of various sizes, it can be easily visualized that the body of the soil would contain solid soil particles through which run minute capillary tubes, which may be partly filled with moisture and partly with air when the moisture conditions are below *salivation* or may be completely filled with moisture when the soil is saturated. It is quite easy to understand that the retention of water would depend upon the size of the capillary spaces. This conception of soil moisture is known as the capillary conception or, 'capillary hypothesis of soil moisture'.

According to the capillary hypothesis of soil moisture relationship the movement of moisture may be expressed by the following relation :—

$$h=2T/gpr \qquad (1)$$

where h is the height to which the water rises in the soil column.

T is the surface tension between water and air.

g is acceleration due to gravity.

p is density of the liquid (water).

r is the radius of the capillary tube.

Substituting the values in C. G. S. system the equation can be reduced to :

$$h=0{\cdot}15/r \qquad (2)$$

When this relationship is applied to a soil column the value of r is the equivalent radius of capillary tubes made up of pore space between the particles of soil. The relation between the radius of capillary tube r and the diameter of the soil particles D of which the soil is made up of has been worked out by Slichter (1898).

$$r=0{\cdot}144\,D \qquad (3)$$

Substituting the value of r in (2)

$$h=\frac{0{\cdot}15}{0{\cdot}144D}=\frac{1}{D} \qquad (4)$$

The value of D is the diameter of soil particles. As all the soil particles are not of the same size, D will represent only the mean diameter.

Thus the height up to which the capillary moisture would rise in a soil column when placed in contact with free water surface would be a reciprocal of the diameter of the soil particle if all the particles are of the same size and of the mean diameter if the soil is made up of particles of various sizes.

Puri [1939] has given experimental evidence in support of this contention and has also shown, that the rise of moisture depends on the capillary forces which change with surface tension, density of the liquid, radius of the particles and temperature.

The extent up to which the moisture can rise has been observed by McGee [1913] up to 10 feet in a year and 30 to 40 feet in favourable period of time.

The capillary potential hypothesis was introduced by Buckingham [1907] who compared the rise of moisture in a soil column to the flow of heat in a metallic bar and of electricity in a wire. The driving force, the capillary force or the capillary potential, was visualized between two particles of soil placed together and at unequal moisture contents. Thus capillary potential is a force of attraction for water in the particles due to which the moisture is sucked and when this force is satisfied no further moisture rise takes place. From the very definition it is clear that the force would be negative and would decrease with the increase of moisture content. The difference between the actual moisture content and the full capillary moisture content would be the measure of the capillary potential.

The capillary potential would be equivalent to the work done to overcome the force of attraction of a soil for water at any point in a soil column, or the amount of work done to move a unit mass of water in a soil column from the free water surface to a given point above the surface. It will be seen that even in the light of the energy relationship of soil moisture retention, the capillary potential would depend upon the factors already mentioned in connection with the capillary hypothesis.

During a study of the movement of moisture and salts in soil columns placed in glazed pipes with the lower ends in water, some observations were made which could not be explained on the ordinary conceptions of movement of capillary moisture. Soil material is of a complex nature and there is every probability of other factors controlling the capillary rise of moisture.

During soil survey work it was observed that salts present in the soil itself or in the sub-soil water differ not only in concentrations but also in nature. The effect of salts on the capillary rise of moisture in soils had been studied by several investigators in the past. Wolkoff's [1920] conclusions were that sodium-chloride decreased the capillary rise of water, and calcium oxide and potassium phosphate showed a tendency to accelerate the water rise. Wollny [1884] found that salts which were most readily absorbed by soils produced little effect on the capillary movement of water, while the non-absorbed salts caused a depression in capillarity. Kravkov [1900] concluded that all salts decreased the capillary rise of water. The order in which water ascended in the presence of various soluble salts was:

$$H_2O > NaNO_3 > Nacl > Na_2\,CO_3 > K_2\,SO_4 > (NH_4)_2\,SO_4 > K_2H\,PO_4 > Na_2\,H\,PO_4$$

For two insoluble salts the order was $CaSO_4 > CaCO_3 > H_2O$. These two insoluble salts hastened the capillary rise. These results are contradictory to the results of Wollny. Briggs and Lapham [1902] determined the effect of three sodium salts, Nacl, Na_2CO_3 and Na_2SO_4 on the capillary rise of water in fine sandy loam soil. Their conclusions were that sodium chloride and sodium sulphate caused very little depression on the capillary rise of moisture, and sodium carbonate slightly accelerated it. Kossovich [1910] found that sodium chloride hastened the rise of water while sodium carbonate hindered the process.

Experimental

The following investigations were carried out to determine their effects upon the capillary rise of moisture.

1. Effect of time and of particle size of sand.
2. Effect of nature of salt present in the water-table.
3. Effect of nature of salt present in the soil column.
4. Effect of nature of exchangeable base and pH value.

I. *Effect of time and of particle size on the capillary rise of moisture*

Sand of varying mean diameter was compacted in different glass tubes of 1·0 in. diameter. A free water-table was provided at the bottom. Observations for the rise of the moisture were taken after frequent intervals. The results are given in Table VII and shown diagrammatically in Fig. 1. The results show that the rate of capillary rise of moisture declines with time and that the ultimate rise is lesser as particles are coarser.

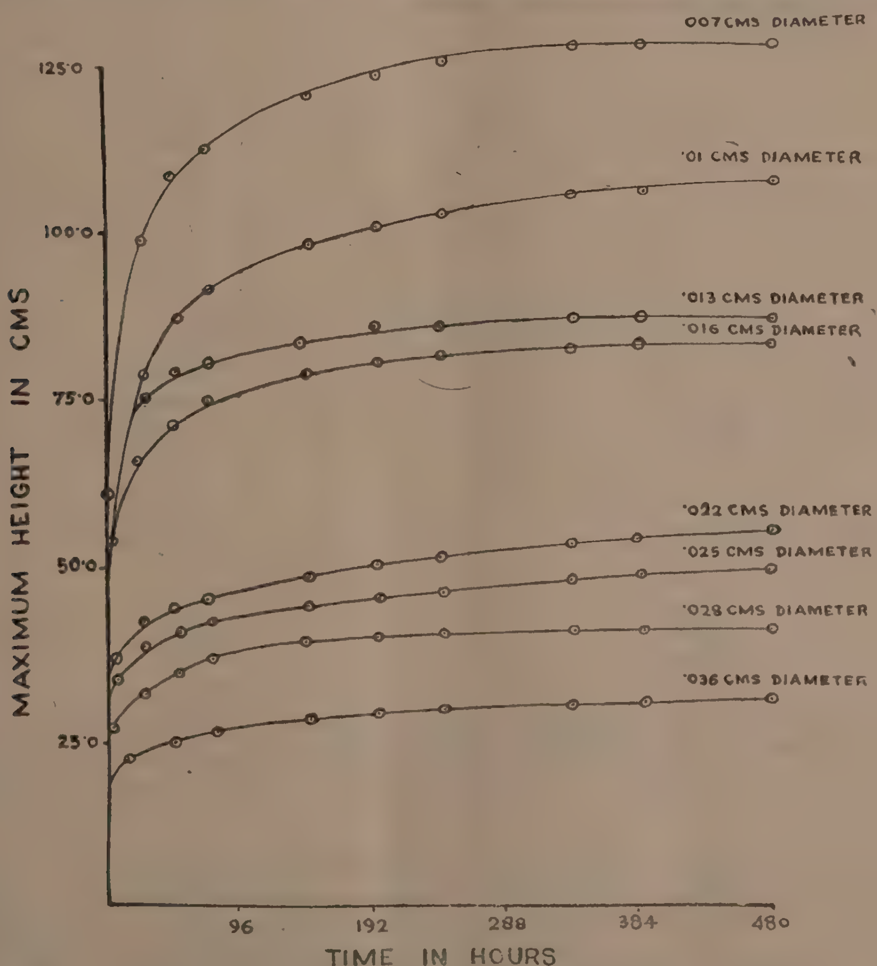

Fig. 1. Showing the effect of time and particle size on the capillary rise of moisture.

A statistical equation has been obtained, connecting the ultimate rise with the mean diameter of soil particles. The ultimate rise is taken as the rise obtained after 20 days. The equation is :

$$h \text{ maximum} = \frac{1{\cdot}792}{d^{0{\cdot}89}} \qquad (5)$$

According to capillary tube hypothesis (11) the maximum height varies inversely as the diameter. In Fig. 2 the graphs for $h=1/d$ and $h=\frac{1{\cdot}792}{d^{0{\cdot}89}}$ have been drawn. Both show quite a nice fit.

All the curves embodying Fig. 1 can be represented by an equation of the type.

$$h = h \text{ maximum } (1 - b^{-td}) \qquad (6)$$

where h is the height attained in centimeters at any time t (t being taken in hours) and h maximum is the maximum height attained as given by equation (5).

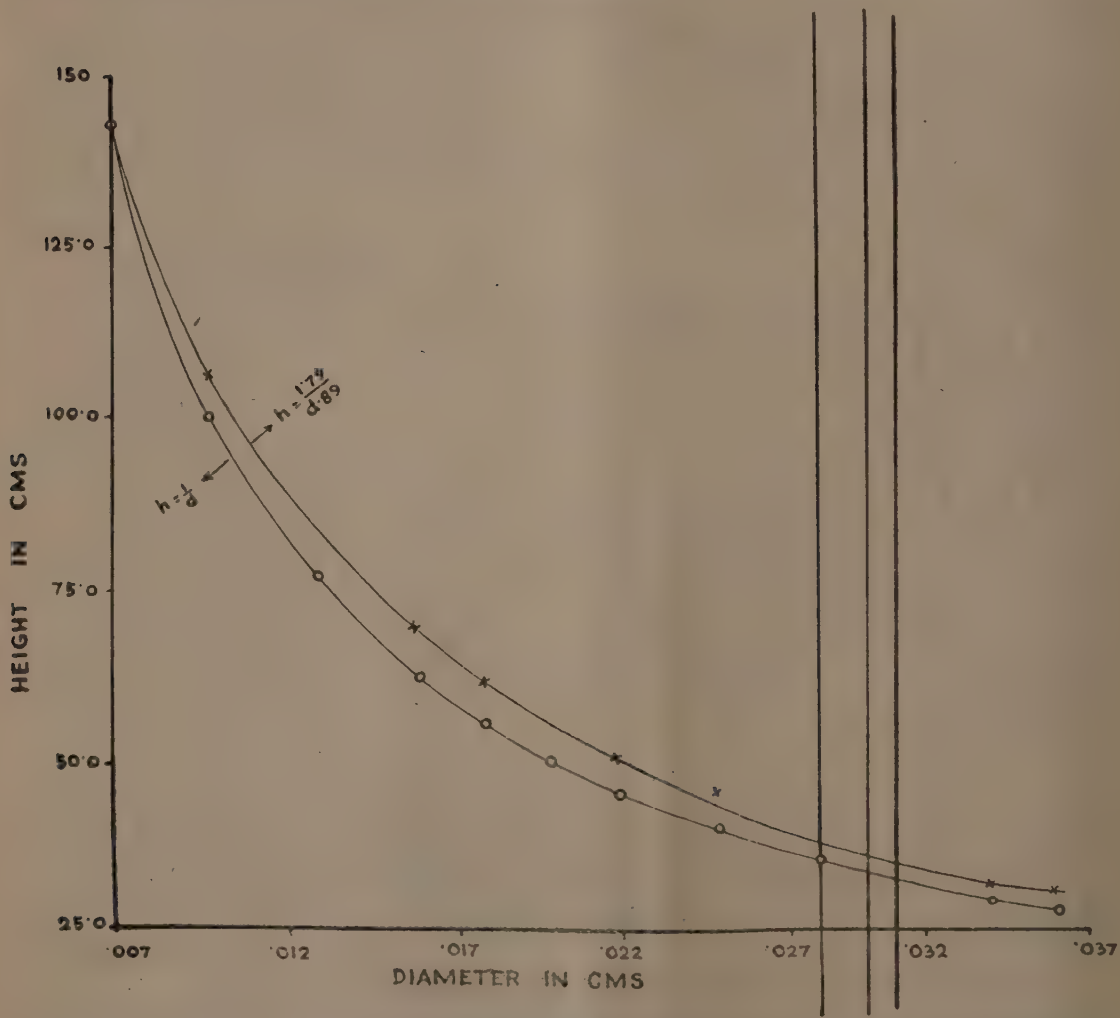

Fig. 2. Showing the agreement between the two curves $L = \frac{1}{d}$ and $h = \frac{1{\cdot}79}{d^{\cdot 89}}$

It has been found that the values of d for the grades of sands of diameter between 0·007 cm. and 0·018 cm. is nearly 0·5 and for the grades between 0·02 cm. and 0·036 cm. is nearly 0·2. The values of b in equation (2) for various diameters with their values of d are given below :

TABLE I

Value of b for various diameters with value of α

Diameter in cm.	α = 0·5 Sand between 0·007 cm. and 0·018 cm. diameters.
·007	1·123
·01	1·236
·012	1·162
·013	1·496
·016	1·718
·018	1·513

TABLE II

Value of b for various diameters with value of α

Diameter in cm.	α = 0·2 Sand between 0·02 cm. and 0·076 cm. diameters.
·02	1·530
·022	2·356
·025	2·787
·028	2·491
·034	1·804
·036	2·073

The values of b do not vary in a regular manner with mean diameter. This may be due to the fact that the rate of rise not only depends on the mean particle size but on other factors such as variation of the soil particles about the mean, the pore space, the density of compaction, and the initial moisture content.

II. *Effect of nature of salt present in the water-table on the capillary rise of moisture*

A typical Punjab soil containing about 16 per cent clay was compacted at 1·5 dry bulk density in five glass tubes of 2·0 in. diameter and 6 feet height. Each tube was provided with a water-table containing one of the following salts in 1 per cent concentration.

1. Sodium chloride
2. Sodium nitrate
3. Sodium carbonate
4. Sodium-bi-carbonate
5. Sodium sulphate

The rise of moisture in each tube from the water-level was noted daily. Curves showing the relation between time and rise of moisture for the various salts are given in Fig. 3.

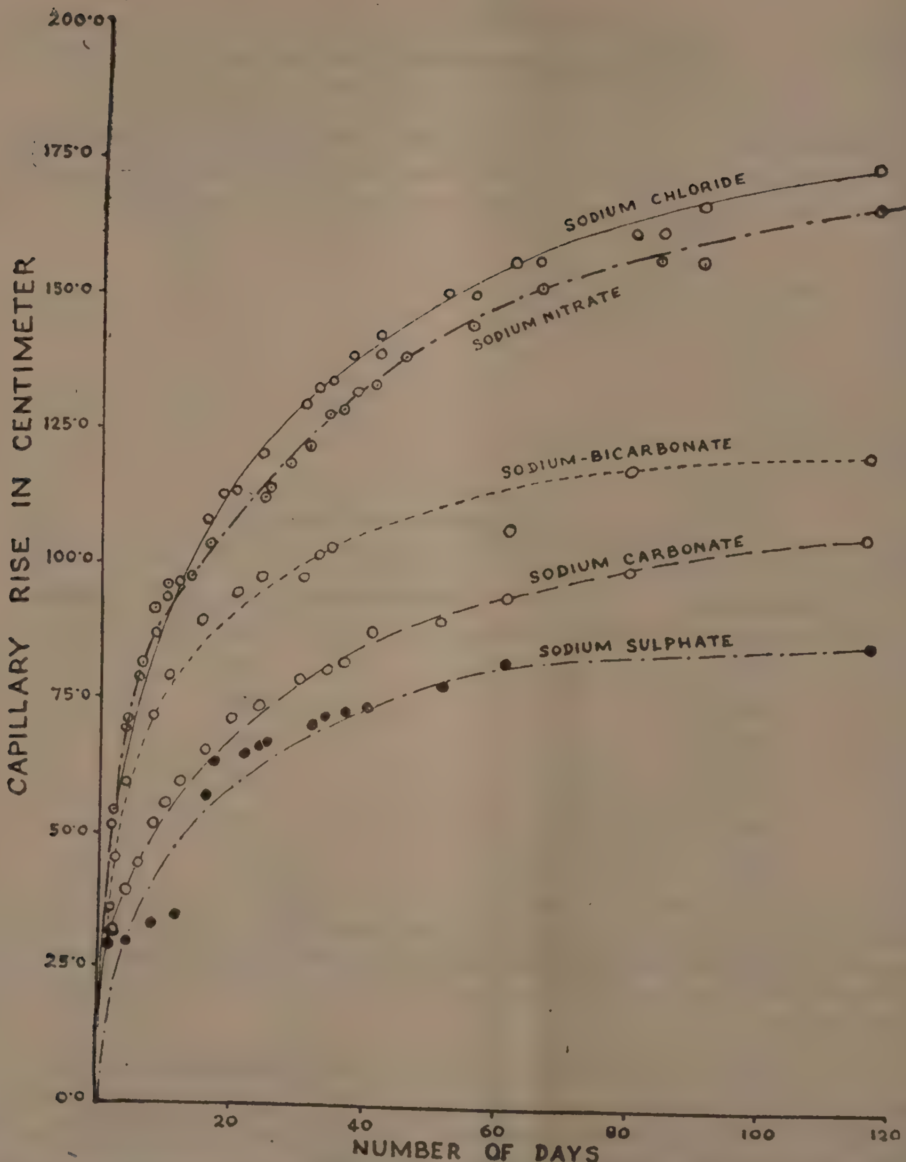

Fig. 3. Showing the effect of time on the capillary rise of varying sodium salt solution in a soil profile compacted at 1·5 dry bulk density.

The rise is the highest in the case of sodium-chloride and sodium nitrate, and lowest in the case of sodium-sulphate and sodium carbonate. Belkin [1940] also found that in a heavy clay sub-soil (passing a 1 mm. sieve) sodium-sulphate rose most slowly. Curini [1939-40] while investigating the changes of capillary rise in arable soil by means of chemical fertilizer observed that the height of capillary rise in filter paper dipped in a soil-suspension was greatest in the nitrateion.

The curves can be expressed in the form $h=a(1-b\text{-}\sqrt{t})$—(7) where h is the height attained in time t and a and b are constants. The values of b in equation (7) for the corresponding values of a, are given below :

TABLE III
The value of b for the corresponding values of a

Serial No.	Nature of salt	Value of b
1	Sodium chloride	1·3878
2	Sodium nitrate	1·3750
3	Sodium-bi-carbonate	1·4598
4	Sodium carbonate	1·3967
5	Sodium sulphate	1·4015

The value of *b* is practically same in all the cases. Table VIII gives the actual and the calculated values of the capillary rise of the solution in sodium-bi-carbonate solution. The agreement between the calculated and the experimental values is excellent.

III. *Effect of the nature of salt present in the soil column on the capillary rise of moisture*

The soil used for experiment No. II was mixed with 1·0 per cent (by weight) of one of the sodium salts and observations were taken for the rise of capillary moisture above a water-table. In this case there was no salt in the water. The curves showing the relations between time and rise of moisture are given in Fig. 4.

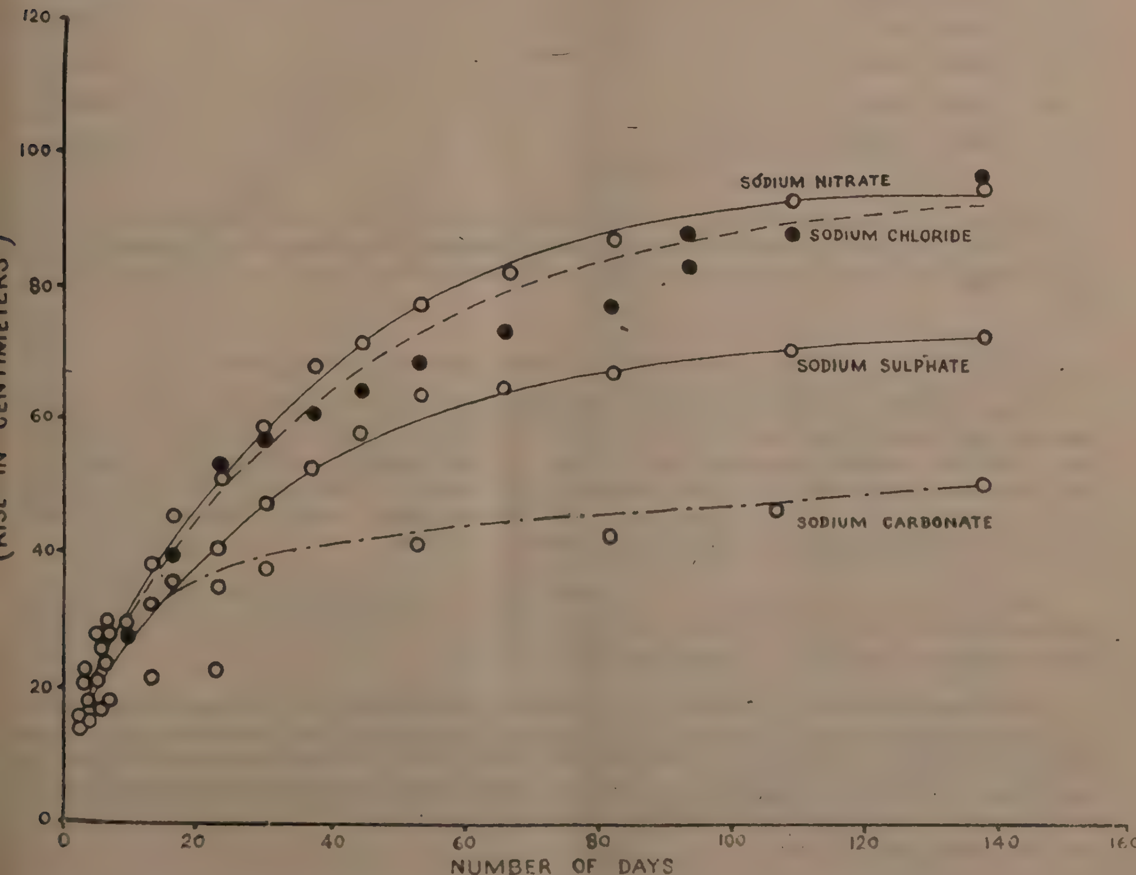

Fig. 4. Showing the effect of the nature of salt present in a soil column on the capillary rise of the moisture.

The maximum capillary rise was different for different salts, but as in the previous experiment it was the highest in the case of sodium chloride and sodium nitrate. The reason seems to be the same as given for experiment No. II.

The shape of these curves indicate a curve of exponential form.

$$h=a\,(1\text{-}b\text{-}\sqrt{t}) \qquad (8)$$

The values of b for the corresponding values of a, are given below:

TABLE IV

The value of b for the corresponding value of a

Serial No.	Nature of salt present in the soil column	Value of b
1	Sodium chloride	1·2067
2	Sodium nitrate	1·3326
3	Sodium carbonate	1·3062
4	Sodium sulphate	1·3002
5	Sodium bi-carbonate	Not given

The value of b is constant in all the cases except sodium chloride where the difference is very small. Table IX gives the actual and the calculated values of the capillary rise of moisture in a soil profile containing 1·0 per cent sodium carbonate. The agreement between the two values is very close.

IV. *Effect of the nature of exchangeable base and pH on the capillary rise of moisture*

The soil used for experiments No. II and No. III was treated with N/20 Hydro-chloric acid for removing the exchangeable bases and then washed with distilled water till it was free from chloride ions. Sodium, potasium, magnesium and calcium soils were prepared at different pH values from the acid treated soil by adding requisite amounts of the respective hydroxides. The soils were then dried, powdered, passed through 1 mm. sieve, and then compacted in glass tubes at 1·5 dry bulb density. A water-table was provided at the bottom of the tubes.

The rise of capillary moisture above the water-table was observed daily. Curves showing the relations between time and rise of moisture are given in Fig. 5. The rise of moisture is low in sodium and potassium soils and high in magnesium and calcium soils.

A fundamental property of soil is that associated with the replacement of bases when it comes into contact with neutral salt solutions. The nature of exchangeable base determines the texture or tilth of the soil to a great extent. When a sodium soil comes in contact with water it goes into suspension. Calcium and magnesium soils do not exhibit such dispersion by auto-disintegration. It will be clear from the following Table that the nature of the exchangeable base has a great influence upon the dispersion of the soil.

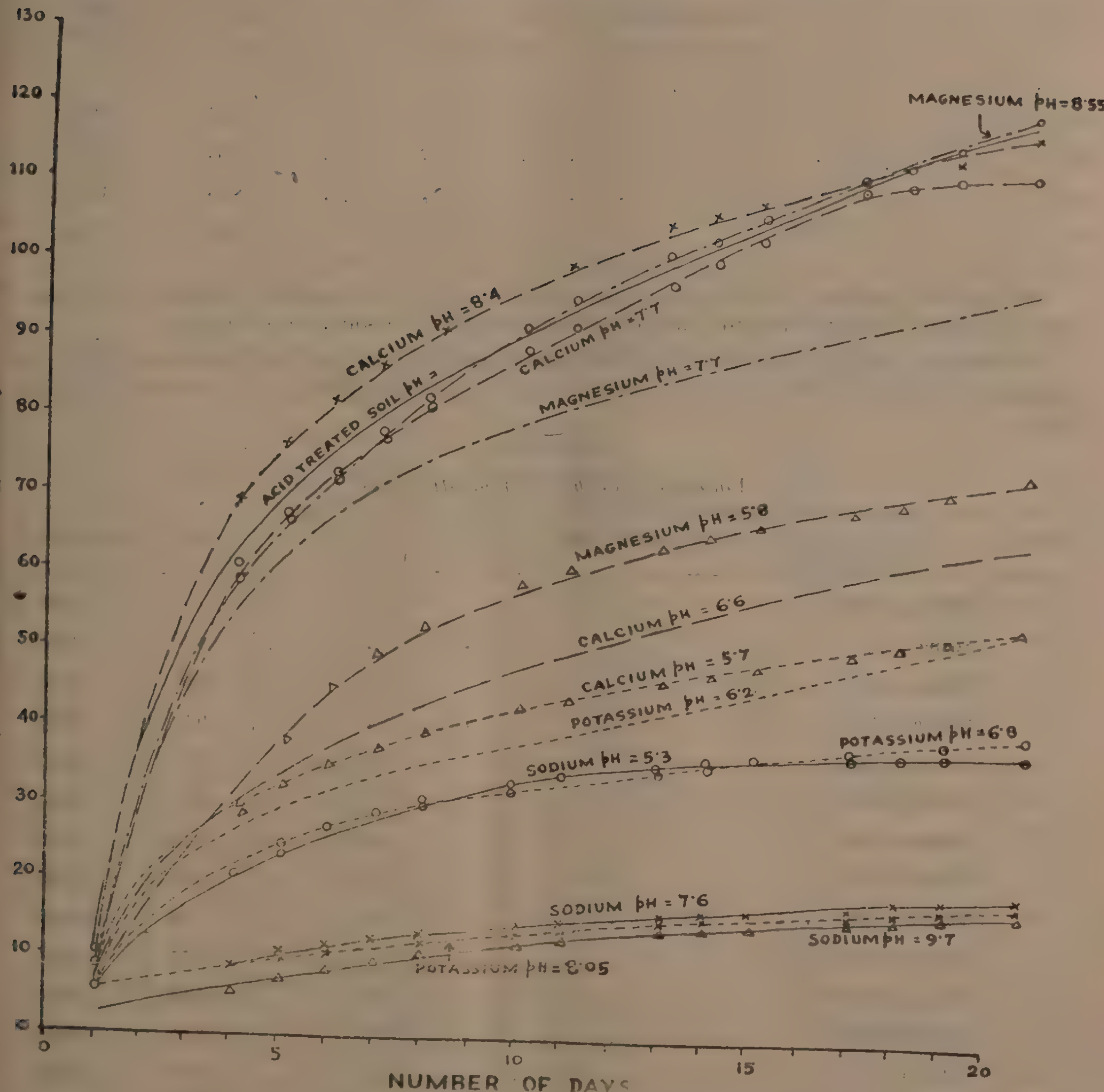

Fig. 5. Showing the effect of exchangeable base 8/p H on the capillary rise of moisture.

I

TABLE V

Effect of the nature of the replaceable base on clay determination

Replaceable base	pH	Clay Per cent
Na	10·66	63·16
K	10·93	24·04
Mg	8·95	13·80
Ca	10·00	6·68

The order of capillary rise of moisture as indicated in Fig. 5 is **opposite.** Sodium and potassium soils have the minimum rise while calcium and magnesium soils the maximum.

The shape of the curves in Fig. (5) is also of the exponential form, and can be represented by an equation $h=a\ (1\text{-}b\text{-}\sqrt{t})$. The values of b for the various soils of different pH values are given below :

TABLE VI

Values of b for the different pH values

Serial No.	Nature of Soil	pH	Value of b
1	Hydrogen soil	..	1·1746
2	Sodium soil	5·3	2·1592
3	Sodium soil	7·6	1·6676
4	Sodium soil	9·7	1·6185
5	Potassium soil	6·2	1·6240
6	Potassium soil	6·8	1·1990
7	Potassium soil	8·05	1·1550
8	Magnesium soil	5·80	1·1806
9	Magnesium soil	7·70	1·1880
10	Magnesium soil	8·55	1·1860
11	Calcium soil	5·65	1·6190
12	Calcium soil	6·60	1·1660
13	Calcium soil	7·80	1·2337
14	Calcium soil	8·40	1·2045

The value of b. decreases with increase in pH value of the Na and K soils, and it is practically same for calcium and magnesium soils except calcium soil of pH 5·65 where it suddenly jumps to 1·6190. The actual and calculated values of capillary rise for a few soils are given in Table X. There is a very close agreement between the two values.

TABLE VII

Effect of time on the capillary rise of moisture in sands of varying grades

S. No.	Mean diameter of sands in cm.	Time in hours								Time in days							
		·25	·75	1	2	3	5	25	71	6	8	10	14	16	20	..	..
		Height attained in centimeters															
1	0·007 . .	6·4	20·7	24·3	39·0	50·0	61·9	98·2	108·6	·113·6	120·7	123·2	125·2	127·8	128·6	129·6	117·8
2	0·010 . .	6·5	17·6	22·6	34·1	43·7	50·6	78·4	87·0	9·1	97·7	100·3	102·5	105·7	106·9	108·9	107·9
3	0·012 . .	7·9	17·9	21·8	33·7	39·5	44·6	61·3	68·3	72·8	79·3	81·9	83·0	85·0	85·8	87·2	91·75
4	0·013 . .	10·1	24·4	27·1	41·7	48·0	52·3	74·0	78·5	80·6	83·9	85·4	86·4	87·0	87·9	87·9	..
5	0·016 . .	13·5	23·5	27·0	36·8	42·5	50·8	66·5	72·0	74·7	78·6	80·2	81·6	83·0	83·9	84·9	..
6	0·018 . .	9·4	17·7	20·8	28·5	33·2	38·6	56·0	64·1	68·2	75·2	78·5	80·8	86·3	87·5	89·4	..
7	0·020 . .	14·3	24·6	24·6	28·0	29·5	31·0	32·0	34·7	37·3	40·3	41·3	41·8	42·3	42·5	42·5	58·24
8	0·022 . .	12·5	20·2	23·2	29·0	32·5	36·8	43·7	44·1	45·4	47·4	48·6	51·6	54·0	54·8	56·7	..
9	0·025 . .	15·5	23·5	24·0	29·5	31·5	33·0	38·7	41·3	42·7	44·7	45·7	46·9	48·3	49·3	50·5	..
10	0·028 . .	20·2	26·2	27·7	28·4	29·4	31·0	33·4	35·1	36·7	39·1	39·9	39·9	41·1	41·3	42·1	43·16
11	0·034 . .	17·2	18·6	19·0	23·0	23·6	25·0	24·7	25·3	26·3	27·9	28·1	29·6	30·6	30·7	31·9	..
12	0·036 . .	14·4	17·0	21·1	22·5	23·4	24·3	27·0	27·4	27·4	27·4	28·6	28·8	29·4	29·8	33·8	34·51

TABLE VIII

Showing the agreement between the actual and the calculated values of the capillary rise of moisture from a solution containing 1·0 per cent of sodium-bi-carbonate

No. of days	Capillary rise in cm. (Actual)	Capillary rise in cm. (calculated from equation No. 7)
1	34·5	38·1
3	53·0	58·2
5	64·5	69·1
7	66·5	76·5
9	76·5	82·1
11	82·0	86·5
15	90·0	93·0
17	93·0	95·6
20	95·0	98·7
24	97·0	102·0
27	97·0	104·0
30	98·5	105·8
34	103·5	107·7
41	105·0	110·3
61	107·0	114·7
79	119·0	116·8
85	120·0	117·3
111	121·0	118·7

TABLE IX

Showing the agreement between the actual and the calculated values of the capillary rise of moisture in soil-profile containing 1·0 per cent sodium carbonate

No. of days	Capillary rise in cm. (actual)	Capillary rise in cm. (calculated from equation No. 8)
2	11·5	10·7
3	15·5	12·6
5	17·7	15·3
6	18·0	16·3
9	18·5	18·7
16	21·0	22·3
23	23·0	24·6
30	24·5	26·1
37	26·5	27·3
44	27·0	28·2
53	27·5	29·1
66	28·5	30·1
82	30·0	31·0
93	30·0	31·4
109	33·5	31·9
138	37·0	32·5

TABLE X

Showing the agreement between the actual and the calculated values of the capillary rise of moisture in a few single base saturated soils

No. of days	Capillary rise in cm. for							
	Calcium soil of *p*H 6·6		Magnesium soil of *p*H 5·8		Potassium soil of *p*H 8·05		Sodium soil of *p*H 7·6	
	Actual	Calculated	Actual	Calculated	Actual	Calculated	Actual	Calculated
1	7·8	9·3	6·8	11·2	6·2	2·5	..	..
4	29·2	29·8	29·0	35·4	..	..	8·7	12·8
5	33·5	34·8	38·0	41·2	9·5	9·8	10·0	13·6
6	37·5	39·1	44·8	46·0	10·5	11·0	11·2	14·3
7	40·5	42·8	49·5	50·2	..	..	12·2	14·8
8	43·5	46·0	53·0	53·7	12·5	13·0	13·0	15·3
10	48·0	51·0	58·2	59·1	13·8	14·5	14·5	16·0
11	50·0	53·0	60·2	61·2	..	..	15·0	16·3
13	53·2	56·2	63·5	64·6	15·2	16·1	16·0	16·8
14	54·5	57·4	65·0	65·9	15·5	16·5	16·5	17·0
15	55·0	58·5	66·0	66·9	..	..	17·0	17·2
17	58·5	60·2	68·5	68·7	17·0	17·4	17·5	17·6
18	60·0	60·9	69·5	69·3	18·4	17·8	18·0	17·7
19	61·0	61·5	71·0	69·9	..	..	18·8	17·8
20	64·5	62·8	73·0	71·1	19·0	18·2	19·5	18·2

Summary

The capillary rise of moisture in soil profiles depends upon various factors, *viz.*

(*a*) The mechanical composition of the soil.

(*b*) The nature of the salt present in the soil profile.

(*c*) The nature of the salt present in the sub-soil water.

(*d*) The nature of the exchangeable base.

The coarser the particle the lesser is the capillary rise. Sodium chloride and sodium nitrate whether present in the soil-profile or sub-soil water, accelerate the capillary rise.

The capillary rise of moisture is high in calcium and magnesium soils and low in sodium and potassium soils.

The curves representing the capillary rise with time exhibit exponential form.

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GROWTH STUDIES ON *SACCHARUM OFFICINARUM* II. IRRIGATION SERIES

By P. C. Raheja, Sugarcane Specialist, Sugarcane Research Station, Tarnab, N. W. F. P.*

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(With three text figures)

IN the Peshawer Valley frosts recur at regular intervals and necessitate growing of early maturing varieties, so that the crop may mature much in advance of setting in of frosts in the cold eason. During the course of growth studies, it had been noticed that varieties exhibited wide variaion in their cumulative growth in length year after year. In years with short formative periods, he grand growth period was extended and that conduced to greater elongation of stalks. With ong formative period, the grand growth period was correspondingly shortened and stalks stunted in umulative growth. Besides, the exponential height growth curves of varieties illustrated that high ucrose varieties generally possessed higher relative rate of growth and that high tonnage varieties ad higher initial rapidity of growth of the crop [Raheja, 1946.] Experiments on irrigation requirenents indicated that critical soil moisture limit irrigation application increased the commercial cane ugar per cent value of the crop compared to the weekly or ten days interval irrigation treatments in pite of the higher cane yield realized by the two latter treatments [Raheja 1944).

These results thus point to the fact that in the peculiar conditions prevailing in this Valley, beides the seasonal factor and the earliness of varieties, water supply to the crop manifests its effect nd it would be of interest to elucidate the relationship between this factor and relative growth rate nd initial potential of growth of the crop.

Agrobiology recognizes that the effect of one growth factor is separable from the action of the thers and that the effect of all the factors, positive and negative, is algebrically cumulative on the evelopment of the plants. Thus, while on the one hand crop varieties or the stabilized agrotypes ave their own physiological constancy, on the other hand, the growth factors have their own consancy. In the normal environment the effectiveness of a given quantity of an external factor of crop rowth, is inversely proportional to its concentration per unit of space [Willcox, 1929]. Having egard to the above we have studied the effect of varying irrigation intervals on the accumulation of rowth and sugar and ultimate yield of the crop. The results available are from those experiments hich were conducted during the seasons 1940-44.

Environment and habitat

The growing season of the crop in this Valley can be conveniently sub-divided into seven periods. he germination period extends over four weeks, which the crop completes by the end of March. he formative period ends about the third week in May and thus lasts for about seven weeks. In this tage the development processes remain active and new buds are laid down and tend to germinate. he grand period stage before earthing up extends over six weeks. The earthing is done in the first eek of July. The remaining grand period stage is finished in the subsequent 13 weeks, when about he first week in October the growth processes appreciably slow down and accumulation of sugar ecomes the main function of the plant. This after nine weeks is succeeded by the frosty period which sts from first week in December to second week in February. In this period growth processes alost come to a stand still and rate of accumulation of sugar is considerably retarded. In the postosty period the ripening process, that is, favourable net assimilation rate, again sets in while subseuent development or suckering chiefly proceeds on at a slow pace. In the sugarcane tract the rop is an irrigated one and rain water as irrigation does not come in for much use. But indirectly manifests its modifying influence a great deal on the crop. In the Valley with small fractions of recipitation high humidity tends to prevail in spite of the high temperature in hot weather. High

* Now Agronomist, Indian Agricultural Research Institute, New Delhi.

maximum temperatures, unless temperatures become supra-optimal, mean favourable conditions of growth. Contrarily low minimums, unless they inhibit physiological activity completely, have their importance in rapid sugar accumulation in the plant.

In Table I the weather data in relation to development stages of the crop, described above, are given for the four seasons of the experimental period. The worked out mean values are shown for the maximum and minimum temperatures, per cent relative humidity and total rainfall for each of the period in different years are set out in Table I. The deviations from the normal have been indicated within brackets except for relative humidity. The normals for relative humidity were not available as observations in the meterological observatory at Peshawar were recorded at 8 0 A.M. instead of 7-0 A.M. In the year 1940-41 the outstanding weather feature was droughty nature of the season during monsoon and autumn months. Rainfall was mostly received during the non-growing period. The following crop season, March, 1941 to February, 1942, again had dry conditions definitely unfavourable during the rapid growing period of this crop. The harvest period, however, was wet which caused considerable delay in harvest. In the third season, similar conditions of drought prevailed in the germination, grand growth period and ripening stages of the crop. In the final year of the experiment, crop experienced stress of drought up to the period before the earthing up of the crop. In grand period stage after earthing up the conditions were definitely favourable for the growth of the plants. In the ripening and frosty period stage low precipitation favoured early harvest.

Generally in the different years variations in mean maximum and mean minimum temperatures were more marked in the germination, and formative periods than in the other development stages of the crop. It is only in the season 1942-43 that the crop experienced severe low temperatures in the frosty period stage. The weather factors for germination in the first season, particularly the low minimum temperatures, were not quite favourable. In the second season the maximum and minimum temperatures, being above normal, influenced germination in a satisfactory way. In year 1942-43 the mean maximum temperature adversely affected germination. In the last season though maximum temperatures were above normal the minimum temperatures exhibited inhibiting influence.

In the formative period of the 1940-41 season both the mean maximum and mean minimum temperatures were below normal. Naturally the development processes leading to high tillering of the crop, were adversely affected. The temperatures in the next season definitely favoured greater tillering of the plants. In the third season the night and day temperatures exhibited the same peculiarity. While the mean maximum temperature favoured the development processes the low minimums limited them. In the crop season 1943-44 both the maximum and minimum temperatures were below the normal for the period and as such inhibited the tillering phase of the crop.

In the grand period stage the relevant temperatures in 1940-41 were the most favourable for rapid elongation of stalks. The high mean maximum temperatures in the second season limited cane growth in the grand period stage before earthing up. Later in the season the growth conditions approximated to the normal. In the third season low maximum countered the unfavourable effect of the low minimums on the elongation processes of the plant. In the last season of the experiment the very low minimum temperatures in the grand period stage before earthing up of the crop adversely affected the early elongation process. However, later on the range of temperatures between mean maximum and mean minimum favourably influenced growth of the crop. A favourable net assimilation balance is brought about by high maximum and low minimum temperatures during the ripening phase of the cane stalks. Generally, the variations in temperatures exhibited in the four seasons were not very different from the normal. On the whole the temperature differences favourably influenced the ripening process except in the crop season 1942-43 when temperatures were definitely unfavourable for cane maturity.

In the 11 weeks of the frosty period the mean maximum and mean minimum temperature approximated more closely to the normal in the three seasons 1940-41, 1941-42 and 1943-44. It is only in the crop season 1942-43 that both the mean maximum and mean minimum temperatures were below normal. During this season no rainfall was received in the months of December and January. As such the crop was harvested early. But the standing seed cane was severely damaged by the frost bite.

TABLE I

Weather relation to development stages of the crop

(*a*) 1940-41; (*b*) 1941-42, (*c*) 1942-43; (*d*) 1943-44

Stage of growth and period.	Mean maximum temperature °F.				Mean minimum temparature °F.				Mean relative humidity per-cent—7·0 Hrs.				Total rainfall inches			
	(*a*)	(*b*)	(*c*)	(*d*)	(*a*	(*b*)	(*c*)	(*d*)	(*a*)	(*b*)	(*c*)	(*d*)	(*a*)	(*b*)	(*c*)	(*d*)
Germination stage (1st week March to 4th week March —4 weeks).	73·8 (—0·7)	79·4 (+4·9)	79·0 (+4·5)	83·3 (+8·8)	48·0 (—4·1)	52·7 (+0·6)	51·4 (—0·7)	46·6 (—5·5)	77	60	83	84	2·89 (+3·44)	0·92 (—1·53)	0·88 (—1·67)	1·13 (—1·32)
Formative period (1st week April to 3rd week May —7 weeks).	84·8 (—4·0)	93·7 (+4·9)	92·6 (+3·8)	87·6 (—1·2)	59·6 (—4·7)	64·1 (—0·2)	56·8 (—7·5)	61·0 (—3·3)	40	39	71	80	3·47 (+1·15)	0·14 (—1·18)	1·67 (+0·65)	0·97 (—1·35)
Grand period stage before earthing up (4th week May to 1st week July — 6 weeks).	102·8 (—1·0)	109·1 (+5·3)	101·7 (—2·1)	102·2 (—1·6)	77·8 (+1·8)	73·5 (—2·5)	71·4 (—4·6)	69·7 (—6·3)	36	35	64	74	0·82 (—0·01)	0·475 (—0·83)	0·475 (—3·53)	0·335 (—0·495)
Grand period stage after earthing up (2nd week July to 4th week September—13 weeks).	97·9 (—0·2)	98·3 (+0·2)	96·0 (—2·1)	96·0 (—2·1)	76·5 (+0·2)	74·8 (—1·5)	72·7 (—3·6)	76·0 (—0·3)	60	58	86	90	0·82 (—3·19)	1·58 (—2·43)	2·135 (—0·875)	5·57 (+1·56)
Ripening stage (1st week October to 4th week November—9 weeks).	85·0 (—0·2)	85·4 (+0·2)	85·1 (—0·1)	85·6 (+0·4)	54·8 (+1·5)	53·1 (—0·2)	51·2 (—2·1)	52·0 (—1·3)	45	47	79	80	0·04 (—0·35)	0·20 (—0·19)	0·555 (+0·165)	.. (—0·39)
Frosty period stage (1st week December to 2nd week February—11 weeks).	67·7 (+2·5)	65·6 (+0·4)	55·1 (—10·1)	66·9 (+1·7)	37·6 (—0·7)	39·1 (+0·8)	33·9 (—4·4)	37·2 (—1·1)	51	75	82	87	0·93 (—2·89	5·99 (+2·17)	1·085 (—2·735)	1·17 (—1·65)

Chemical analyses of the soil in which the experiments were planted are given in Table II below.

TABLE II

Chemical soil analysis of experimental blocks

Chemical constituents	1940-41 and 1942-43 Block-B Per cent on air dry basis	1941-42 and 1943-44 Block-A Per cent on air dry basis
Moisture	0·525	0·700
Loss on ignition	2·375	2·12
Kjeldahl nitrogen	0·050	0·126
P_2O_5	0·179	0·185
K_2O	0·531	0·487
CaO	10·08	8·75
Fe_2O_3	5·16	6·60
Al_2O_3	1·661	1·365
KCl and NaCl	2·88	3·045
MgO	1·50	1·25
Sulphates	0·06	0·085
Chlorides	0·0035	0·004
Silicates	6·25	3·05

The principal difference in the soils of the two blocks was in the content of kjeldahl nitrogen. It was almost double in block 'A' compared to that the soil of the other block. The difference in organic matter, as evidenced by loss on ignition, phosphoric acid and potash content are observed to be small.

FIELD PRACTICE

In the experimental field a four course rotation in two years was adopted and is given below:

Cowpeas--Maize--Clover—Sugarcane

In the rotation cowpeas and clover (*Trifolium resupinatum*) were green manured respectively for maize and sugarcane crops. Thus sugarcane crop in 1940-41 and 1942-43 was on blocks 'B' and in 1941-42 and 1943-44 was on block 'A' of the farm. The planting was usually done in March when the environment becomes suitable. The common practice is to plant cane in clover at three feet interspace. This standard practice was adopted for normal plantings. The planting dates of the various experiments are set in in Table II.

TABLE III

Planting dates of experiments

Particulars of experiments	Crop seasons			
	1940-41	1941-42	1942-43	1943-44
I. Irrigation intervals × Nitrogen levels × Methods of planting.	20/4	1/4	29/3	21/3
II. Irrigation intervals × Top dressings × Basal treatments	29/3	29/3	20/3	27/3
III. Irrigation intervals × Varieties × Periods of planting	..	27/11 and	1/3	..

The variations in the planting dates were unavoidable due to circumstances beyond control. Chief causes were interference due to untimely rains and unavailability of water on due dates.

Clover is ploughed in in the end of May when in bloom. In June usually two intercultivation- are given to the sugarcane crop and as a matter of routine these were given following each irrigation after mid-June. This is followed by earthing up in the first week of July. This was done with implements. The crop usually does not receive any further cultural operation. Irrigations were applied according to the schedule laid down for each of the experiments. Harvesting of the experiments was carried out usually in January every year and this extended up to mid-February depending upon the weather conditions prevailing on each occasion.

EXPERIMENTAL

In the first article of this series the method of measuring growth in length has been described [Raheja, 1946]. The same was adopted in these studies also. In the *Irrigation intervals × Methods of planting × Nitrogen levels* and *Irrigation intervals × Top dressing × Basal dressings* experiments the three irrigation treatments compared were weekly, ten days and critical soil moisture limit. The critical soil moisture was determined when active plant growth tended to slow down and the growth curve had a tendency to run parallel to the absissa [Raheja, 1946]. When such a limit of soil moisture was reached irrigation to the crop was applied. In all cases measured quantity of two acre inches of water was applied to the field at intervals stated above. After one month of the planting the differential treatments were begun. The application of water at these intervals was continued to the end of November. In the case of weekly and ten days interval treatments for every 0·2 in. of rainfall received between two intervals, the irrigation was delayed by a day. This arbitrary procedure for rainfall evaluation was adopted in the absence of workable rules based on day degree irrigation control which has since been initiated by Swezey [1942]. These arbitrarily fixed limits have served a commonsense factor of safety in the experimental work.

In the *Irrigation intervals × Varieties × Periods of planting* series the two irrigation treatments compared were weekly and critical soil moisture limit. Although the experiment remained in progress for all the three years the observational record could be maintained in the year 1941-42 which is reproduced and discussed below. In the former two $(3)^3$ confounded experiments the shoots for the study of growth measurements were labelled in one representative block of nine plots, out of the six planted for each of the experiments. The cumulative growth in length curves and its exponential curves for working out the growth constants were obtained from the mean values of the record obtained from the ten mother shoots which had been selected for the purpose. In all these experiments growth curves were fitted in the manner outlined in the preceding paper.

RESULTS OF INVESTIGATIONS

A. *Cumulative growth in length*

I. *Irrigation intervals × Nitrogen levels × Methods of planting experiment*

In the experiment besides the three irrigation intervals, the three levels of nitrogen tested were 50, 100 and 150 lb. The doses of nitrogen were applied at planting in the form of farm compost. The three methods of planting compared were (*a*) local system on flat in clover in furrows opened with the country plough ; (*b*) planting setts in furrows 7-9 in. deep with a covering of 1/2 in. of soil and (*c*) planting in furrows 7-9 in. deep and completely covering the setts by levelling the two side ridges. In the first treatment green manuring with clover crop was done in mid-May when it was in bloom while in the latter two the clover crop was used for green manuring in the month of February. The observations on growth in length are summarized as under :

TABLE IV

Summarized cumulative growth in length data in cm.
(I_0 *weekly interval,* I_1*—Ten days interval,* I_2*—Critical soil moisture limit interval*)

Crop season	Irrigation interval	Growth months						
		April and May	June	July	August	September	October	November
1940-41	I_0	6·64	18·77	56·04	110·41	144·25	167·08	171·73±31·6
	I_1	6·17	16·06	43·89	93·85	123·41	140·88	145·76±24·02
	I_2	6·76	17·44	46·57	95·85	123·68	140·18	145·32±19·69

NOTE.—Treatment differences between November heights not significant.

1941-42	I_0	17·26	40·59	113·64	174·20	216·77	227·38	234·64±10·157
	I_1	17·00	35·95	102·52	165·38	205·97	214·71	220·89±36·14
	I_2	17·58	32·00	90·63	151·08	189·45	197·25	202·80±7·018

NOTE.—Treatment difference between I_0 and I_2 significant at $P=0·05$ for the November heights.

1942-43	I_0	21·55	59·73	117·80	183·29	228·38	260·38	272·03±23·14
	I_1	19·59	45·40	92·98	159·87	200·12	228·35	238·09±14·04
	I_2	18·71	39·95	87·30	150·03	186·88	216·17	226·91±16·87

NOTE.—Treatment difference between I_0 and I_2 significant at $P=0·05$ and between I_0 and I_1 at $P=0·2$.

1943-44	I_0	..	25·25	107·21	164·87	208·86	219·14	223·88± 8·19
	I_1	..	23·84	91·82	141·41	193·09	204·41	209·61±14·36
	I_2	..	24·43	96·19	151·36	198·89	209·33	213·08±13·15

NOTE.—Treatment difference between November heights not significant.

The data of cumulative growth in length have been compiled on progressive monthly basis and results up to the month of November have been set out in Table VII. A comparison of the results for the various years indicates that best the cumulative growth was shown in the year 1942-43. It was the

poorest in the crop season 1940-41. The initial start of the crop, *i.e.* accumulated growth up to end of May served as a good indicator as to the likely performance of the crop in the season. The early start in the season was very poor in the year 1940-41 and very rapid in the season 1942-43. Between the crop seasons 1941-42 and 1943-44 the growth was somewhat less vigorous in the latter year compared to the former and this difference was reflected in final height attained by the crop in the former year (Fig. 1). Evidently, the mean growth accumulated within the grand growth period was the same in the two seasons. Thus initial start is an important factor in the growth in length accumulation of the crop.

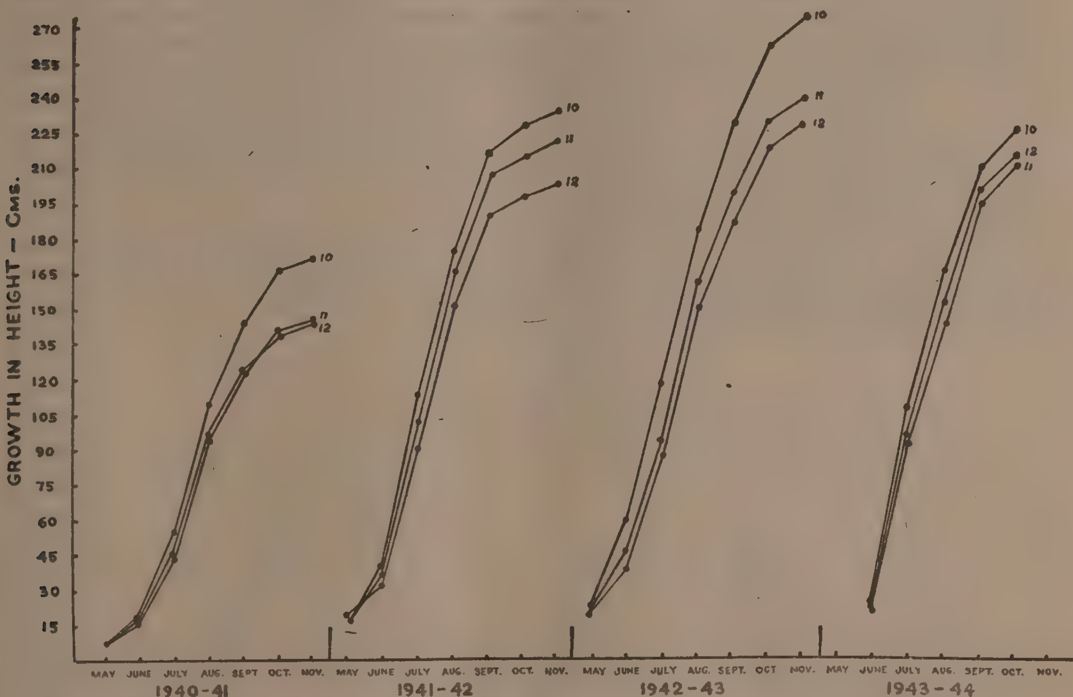

Fig. 1. Cumulative growth in length (Irrigation intervals × Nitrogen levels & Methods of planting series)

In all the years, weekly interval irrigation treatment indicated better accumulation of growth than the other two treatments. The differences were not appreciable in the ten days and critical soil moisture interval treatments in the year 1940-41. The growth accumulated was greater with ten days interval irrigation treatment in the next two seasons but it was slightly less in the final year.

For the final heights attained in November standard error of the mean for each of the figures was worked out. It is evident that in all the years and for most of the treatments the degree of variation for height of stalks was fairly large. Thus the differences between the mean values were only occasionally significant.

2. *Irrigation intervals × Basal treatments × Top dressings series*

In this experiment the basal treatments consisted of using clover for green manuring as against fallow dressed with farm compost. Treatment B_0 consisted of green manuring clover when in bloom, that is in mid-May. In the case of B_1 the clover was buried in in February when it was ready for second cutting on soils of average fertility. Third treatment, that is B_2, for comparison consisted of

fallow dressed with farm compost. These three treatments —B_0, B_1 and B_2, along with three irrigation treatments and three top dressing treatments were confounded with blocks. The three top dressing treatments consisted of three local practices prevailing in the different parts of the sugarcane tract. In the major portion of Charsada tehsil of Peshawar district abundant supplies of water are available for growing sugarcane and the crop is top dressed with heavy doses of manure. The analysis of the materials applied indicates an equivalent of 125 lb. nitrogen per acre (M_0). In the Peshawar tehsil and Mardan district the amounts of materials applied as top dressing have nitrogen content of an equivalent of about 100 lb. per acre (M_1). In both cases, the variety of materials applied ranges from farmyard manure to earth from dilapidated mud buildings. The farmyard manure showed an analysis of about 1 per cent nitrogen, compost about 0·50 per cent, earth from the historical ruins about 0·25 per cent and earth from dilapidated mud buildings and silt from canals about 0·01 per cent nitrogen content. As standard for comparison against M_0 and M_1 treatments, M_2 consisted of an application of 75 lb. nitrogen and 75 lb. P_2O_5 applied as ammonium sulphate and *shora* bone meal. The latter product is prepared by mixing bone meal and crude potassium nitrate. The mixture in the ratio of 1 : 3 in wet condition is allowed to mature in vats over a period of five months when it is sun dried (7·5 per cent moisture) and bagged. Its several analysis showed 3-4 per cent nitrogen and 19-20 per cent phosphoric acid.

There were two replications of the experiment. In each of the replications there were three blocks of nine plots each. Experimental data were recorded on ten plants in every one of these plots. Growth in length studies were conducted in nine plots of one of the representative blocks out of six blocks in two replications of the experiments.

TABLE V

Summarized cumulative growth in length data in cm.

(I_0 Weekly interval, I_1—Ten days interval, I_2—Critical soil moisture limit)

Crop season	Irrigation interval	Growth months						
		April and May	June	July	August	September	October	November
1941-42	I_0	25·00	59·34	116·02	186·06	233·42	261·69	272·68±16·83
	I_1	23·42	56·98	101·85	175·53	211·60	238·30	249·54±12·45
	I_2	22·31	56·28	133·65	182·84	211·07	247·27	259·26±16·63

NOTE.—Treatment differences between November heights not significant

Crop season	Irrigation interval	April and May	June	July	August	September	October	November
1942-43	I_0	16·13	29·84	91·49	157·96	209·38	217·13	223·43±16·28
	I_1	15·08	25·79	79·06	148·75	196·46	204·62	210·91±21·98
	I_2	14·21	23·92	70·04	130·45	166·67	174·97	181·12±21·91

NOTE—Treatment differences between November heights of I_0 and I_2 significant at P=0·05.

Crop season	Irrigation interval	April and May	June	July	August	September	October	November
1943-44	I_0	..	24·38	86·26	145·62	191·99	202·74	205·50±13·67
	I_1	..	20·32	77·58	130·82	171·85	182·54	184·67±13·94
	I_2	..	18·57	71·34	128·02	169·79	179·83	182·57±12·82

NOTE.—Treatment differences between November heights of I_0 and I_1 and I_0 and I_2 significant at P=0·2

A comparison of the growth in length in the three seasons indicates that the cumulative growth in length was the highest in the crop season 1941-42 and the lowest in the season 1943-44, irrespective of the treatment difference. Weekly interval irrigation treatment in all the three cases exhibited the best growth. In the first season between the two treatments, I_1 and I_2, the rate of growth accumulation was the same up to the end of June; in July a difference of about 13 cm. occurred which could not be made good till the end of November. Thus ten days interval treatment showed lesser growth accumulation than critical soil moisture limit by about 10 cm. In the following crop season application of irrigation at critical soil moisture limit evidenced slower rate of growth accumulation throughout the growing season of the crop. By the end of November the accumulated height was short by 30 cm. in the critical soil moisture limit treatment. In the final season the differences in accumulated growth at all the stages in the life-cycle of the plants between treatments I_1 and I_2 were small and the stand of the crops by the end of November was about equal.

Up to the end of the formative period (Fig. 2) critical soil moisture limit treatment had the least growth in height in the crop season 1941-42. Thereafter it rapidly progressed and even was somewhat greater than ten days interval, which treatment began to show lag immediately the formative period was over. In the crop season 1942-43 (Fig. 3) the differences in growth amongst the treatments, apparent in the formative period, were also evident in the bloom and the senescent stages of the crop. Weekly interval treatment maintained a lead through the three stages of growth. In the final year at the close of the formative period weekly stage interval treatment had the highest and the critical moisture treatment the lowest stand. Thereafter the weekly interval treatment curve of growth continued to differentiate away from the ten days interval curve. The latter curve, however, kept close to the critical soil moisture treatment curve.

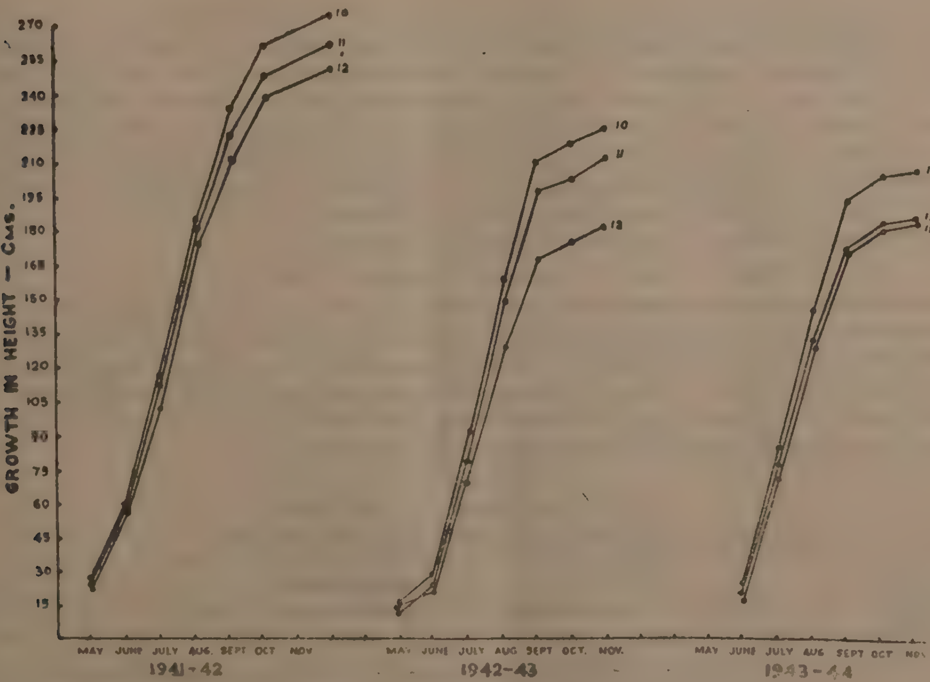

Fig. 2. Cumulative growth in length (Irrigation levels × basal treatments × dressing series)

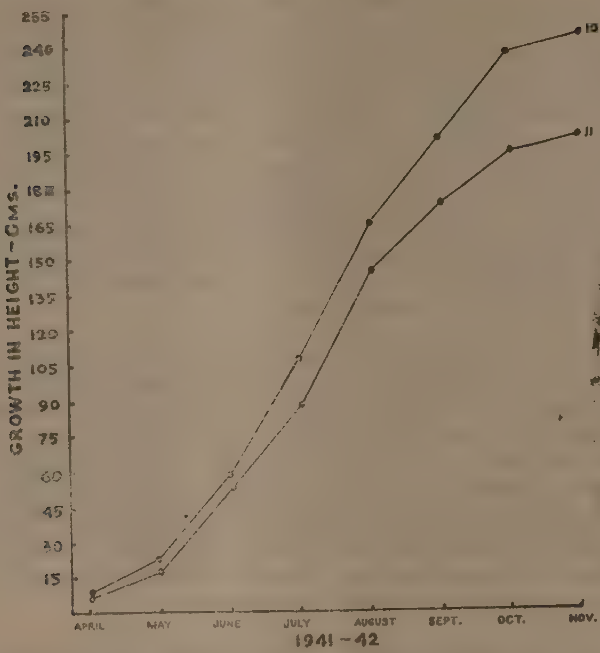

Fig. 3. Cumulative growth in length (Irrigation intervals × varieties × periods of planting)

Growth in length data of the final mean heights in November for the various treatments were subjected to statistical treatment. The standard errors of the mean values have been shown in Table V. In the year 1941-42 the stalk height variations were disproportionately large and reatment differences were not significant. In the following year the differences between the treatment means for I_0 and I_2 were very wide, and in spite of the high degree of stalk height variation, the difference was significant. In the final year the stalk to stalk height variation was not so large as in the preceding year. The treatment means exhibited significant differences between I_0 and I_1 on the one hand and I_0 and I_2 on the other at 20 per cent level of significance only.

3. *Irrigation intervals × periods of planting × varieties*

Besides the two irrigation treatments, two periods of planting and two varieties were also compared in this experiment. In the autumn period sugarcane was planted on the 27 November after harvesting the preceding maize crop on the 13 November, 1940. The corresponding date of planting for the spring crop was March, 1941. The two varieties compared were Co. 290 (standard) and Co. 312. The experiment was a complex one laid out on randomized block system which had six replications. The cumulative growth in length data are summarized as under :

TABLE VI

Cumulative growth in length data

(I_0-Weekly interval ; I_1—Critical soil moisture limit)

Irrigation interval	Growth months							
	April	May	June	July	August	Sept.	Oct.	Nov.
I_0	10·49	23·13	58·73	106·53	165·04	205·85	237·96	245·17±17·95
I_1	8·82	18·99	52·10	88·60	145·49	173·59	196·82	202·72±27·18

NOTE.—Treatment difference between mean November heights significant at P= 0·10

The curves of cumulative growth have been illustrated in Fig. 3. It is evident that small differ-ences in the initial stages of growth progressively tended to increase and it is observed that with cri-ical soil moisture limit treatment the bloom stage tended to decline more quickly than in the case of veekly interval as the plants tended to enter their senescent stage of growth. This wide difference in he ultimate height, which was significant at 10 per cent level of significance, attained between the wo treatments, made an equally great difference in the ultimate yield. By the former treatment the ield decreased by 233 maunds compared to the latter.

B. *Exponential Height Growth Curves*

1. In the *Irrigation intervals × Methods of planting × Nitrogen level* experiment the logrithmic alues of the growth in length figures when graphed, showed the curves to have exponential type. These were, therefore, fitted mathematically and the summary of the results for all the years has been iven in Table VII.

Besides working out the exponential height growth curves, to derive values of relative growth ate and the initial potential of growth, mean daily growth rate and C.C.S. values of the crop record-d in the various treatments have also been summarized. All these have been briefly given in Table III for comparison and interpretation.

TABLE VII

Exponential height growth curves $H=Ae^{bt}$

Treat-ment	1940-41 equation $H=Ae^{bt}$	S.E. of 'b'	Treat-ments	1941-42 equation $H=Ae^{bt}$	S.E. of 'b'	1942-43 equation $H=Ae^{bt}$	S.E. of 'b'	1943-44 equation $H=Ae^{bt}$	S.E. of 'b'
$M_0\ N_0$	$H=10{\cdot}94e^{0{\cdot}0133t}$	±0·001239	$I_0\ M_0\ N_1$	$H=9{\cdot}26e^{0{\cdot}0179t}$	±·000966	$H=9{\cdot}77e^{0{\cdot}0122t}$	±0·00088	$H=15{\cdot}5e^{0{\cdot}0124t}$	±0·001237
$M_1\ N_1$	$H=10{\cdot}29e^{0{\cdot}0122t}$	±0·000492	$I_0\ M_1\ N_2$	$H=9{\cdot}93e^{0{\cdot}0177t}$	±0·000789	$H=9{\cdot}75e^{0{\cdot}0169t}$	±0·001318	$H=12{\cdot}43e^{0{\cdot}0132t}$	±0·001215
$M_2\ N_2$	$H=12{\cdot}71e^{0{\cdot}0126t}$	±0·001102	$I_0\ M_2\ N_0$	$H=9{\cdot}58e^{0{\cdot}0177t}$	±0·001000	$H=8{\cdot}74e^{0{\cdot}0166t}$	±0·000531	$H=12{\cdot}90e^{0{\cdot}0128t}$	±0·001287
$M_0\ N_2$	$H=8{\cdot}46e^{0{\cdot}0159t}$	±0·000661	$I_1\ M_0\ N_2$	$H=10{\cdot}74e^{0{\cdot}0171t}$	±0·000625	$H=6{\cdot}95e^{0{\cdot}0176t}$	±0·000993	$H=10{\cdot}93e^{0{\cdot}0136t}$	±0·001188
$M_1 N_0$	$H=14{\cdot}55e^{0{\cdot}0121t}$	±0·000492	$I_1\ M_1\ N_0$	$H=7{\cdot}08e^{0{\cdot}0177t}$	±0·000525	$H=10{\cdot}03e^{0{\cdot}0156t}$	±0·000813	$H=9{\cdot}69e^{0{\cdot}0134t}$	±0·002971
$M_2\ N_1$	$H=9{\cdot}03e^{0{\cdot}0137t}$	±0·000907	$I_1\ M_2\ N_1$	$H=\cdot8{\cdot}24e^{0{\cdot}0170t}$	±0·000381	$H=9{\cdot}19e^{0{\cdot}0160t}$	±0·000542	$H=12{\cdot}70e^{0{\cdot}0129t}$	±0·0001160
$M_0\ N_1$	$H=7{\cdot}09e^{0{\cdot}0161t}$	±0·000727	$I_2\ M_0\ N_0$	$H=8{\cdot}94e^{0{\cdot}0154t}$	±0·000479	$H=6{\cdot}93e^{0{\cdot}0156t}$	±0·00086	$H=12{\cdot}16e^{0{\cdot}0132t}$	±0·002320
$M_1\ N_2$	$H=10{\cdot}99e^{0{\cdot}0117t}$	0·001093	$I_2\ M_1\ N_1$	$H=8{\cdot}44e^{0{\cdot}0171t}$	±0·000673	$H=9{\cdot}31e^{0{\cdot}0156t}$	±0·000796	$H=9{\cdot}86e^{0{\cdot}0136t}$	±0·001278
N_0	$H=10{\cdot}85e^{0{\cdot}0127t}$	±0·001264	$I_2\ M_2\ N_2$	$H=8{\cdot}34e^{0{\cdot}0175t}$	±0·000760	$H=8{\cdot}72e^{0{\cdot}0162t}$	±0·000869	$H=12{\cdot}86e^{0{\cdot}0136t}$	0·001290

TABLE VIII

Interrelated growth constants, yield and C.C.S. per cent values
(I_0—Weekly interval, I_1—Ten days interval, I_2—Critical soil moisture limit interval)

Crop season	Irrigation interval	Mean parameter 'A' values	Mean daily growth rate	Mean yield md. P.A.	Mean parameter 'b' values	Mean C.C.S. value per cent
1940-41	I_0	11·31	0·01690	495	0·0127	..
	I_1	10·73	0·01623	453	0·0139	..
	I_2	9·64	0·01608	419	0·0135	..
1941-42	I_0	9·56	0·01727	649	0·01776	6·20
	I_1	8·69	0·01584	701	0·01724	5·47
	I_2	8·57	0·01536	551	0·01666	7·23
1942-43	I_0	9·42	0·01514	754	0·01520	6·20
	I_1	8·72	0·01479	757	0·01640	6·84
	I_2	8·32	0·01418	743	0·01613	6·83
1943-44	I_0	13·61	0·01490	717	0·01270	10·07
	I_1	10·83	0·01470	767	0·01333	10·28
	I_2	11·63	0·01494	648	0·01343	10·51

In general it may be noted that in all the years mean parameter 'A' values for the weekly interval treatment were higher than the other two treatments and in three out of four trials the ten days interval values were higher than the critical soil moisture stage irrigation treatment. Mean daily growth rate values, in majority of the cases, were higher in the case of weekly interval treatment compared to the ten days or wilting stage treatments. Mean daily growth rate readings of the ten days interval were higher than wilting stage treatment in three out of four cases. In the first paper of the series it has been shown (1946) that mean parameter 'A' values are highly correlated to the cane yield factor. In the above results, however, a close correspondence between parameter 'A' values and the mean yields have not been observed.

In the first year the mean parameter 'b' value was the highest in the case of ten days interval treatment. This value was not materially different from that obtained with critical soil moisture limit irrigation treatment. The lowest value was shown by the weekly interval irrigation. The data on *Commercial Cane Sugar* value per cent were not recorded. In the year 1941-42 mean value for parameter 'b' was the highest for weekly interval and lowest for wilting stage treatment while mean *Commercial Cane Sugar* per cent value was the highest in the wilting stage and lowest for ten days interval. Thus there was no direct correspondence between the parameter 'b' and mean *Commercial Cane Sugar* per cent values. In the third year the relative growth rate values were the highest in the ten days interval treatment and lowest in the weekly interval treatment. The difference between ten days and critical soil moisture limit treatment was very small. In *Commercial Cane Sugar* per cent values difference between the two treatments was negligible. In the final year the mean parameter 'b' or relative growth rate values were of the order expected, *i.e.* weekly, ten days and critical soil moisture limit treatment. The mean *Commercial Cane Sugar* per cent values for the three treatments exhibited similar values. Thus a close correspondence between parameter 'b' and *Commercial Cane Sugar* per cent values was indicated.

2. The exponential height growth curves data of the *Irrigation intervals / Basal treatments / Top dressing series* are summarized in Table IX of the text.

A summary of the results of cane yield, *Commercial Cane Sugar* per cent values and growth constants derived from the exponential height growth curves and mean daily growth rate of the various treatments are given in Table X.

TABLE IX

Exponential height growth curves

Treatment	1941-42 equation $H = Ae^{bt}$	S.E. of 'b'	Treatment	1942-43 equation $H = Ae^{bt}$	S.E. of 'b'	Treatment	1943-44 equation $H = Ae^{bt}$	S.E. of 'b'
$I\ B\ M$ . .	$H = 9.14e^{0.0179t}$	± 0.000674	$I_0 B_0 M_0$ . .	$H = 5.27e^{0.01861t}$	± 0.0009564	$I_0 B_0 M_1$	$H = 12.06e^{0.01330t}$	± 0.001142
$I\ B\ M_1$	$H = [illegible].65e^{0.0173t}$	± 0.000305	$I_0 B_1 M_1$ . .	$H = 5.60e^{0.01884t}$	± 0.0008963	$I_0 B_1 M_0$	$H = 11.49e^{0.01376t}$	± 0.001091
$I_1 B_2 M_0$.	$H = 9.89e^{0.0174t}$	± 0.000320	$I_0 B_2 M_2$ . .	$H = 5.50e^{0.01728t}$	± 0.0007508	$I_0 B_2 M_2$	$H = 11.79e^{0.01365t}$	± 0.00171
$I_1 B_1 M_0$ . .	$H = 9.11e^{0.0179t}$	± 0.001305	$I_1 B_0 M_2$ . .	$H = 5.68e^{0.01734t}$	± 0.0007466	$I_1 B_0 M_2$	$H = 11.04e^{0.01308t}$	± 0.001163
$I_1 B_1 M_1$ . .	$H = [illegible].91e^{0.0169t}$	± 0.001132	$I_1 B_1 M_0$	$H = 4.99e^{0.01776t}$	± 0.0008220	$I_1 B_1 M_1$	$H = 7.07e^{0.01344t}$	± 0.001257
$I_1 B_1 M_2$ . .	$H = [illegible]e^{0.0176t}$	± 0.001249	$I_1 B_2 M_1$ . .	$H = 4.56e^{0.01888t}$	± 0.0008983	$I_1 B_2 M_0$	$H = 10.37e^{0.01399t}$	± 0.001203
$I_2 B_1 M_2$ . .	$H = 7.93e^{0.0174t}$	± 0.000277	$I_2 B_0 M_1$ . .	$H = 4.96e^{0.01773t}$	± 0.0008148	$I_2 B_0 M_0$	$H = 11.55e^{0.01281t}$	± 0.001604
$I_2 B\ M$.	$H = [illegible].47e^{0.0186t}$	± 0.002375	$I_2 B_1 M_2$ . .	$H = 4.57e^{0.01735t}$	± 0.0007612	$I_2 B_1 M_2$	$H = 7.66e^{0.01425t}$	± 0.001158
$I_2 B_2 M_1$ . .	$H = [illegible].62e^{0.0166t}$	± 0.000763	$I_2 B_2 M_0$ . .	$H = 3.89e^{0.01863t}$	± 0.001472	$I_2 B_2 M_1$	$H = 7.73e^{0.01512t}$	± 0.001481

TABLE X

Interrelated growth constants, yield and commercial cane sugar per cent values

(I_0—weekly interval, I_1—ten days interval, I_2—critical stage moisture limit)

[illegible]	Treatments	Mean parameter 'A' values	Mean daily growth rate	Mean parameter 'b' values	Mean C.C.S. per cent values	Mean yield md. Per Acre
1941-42 .	I_0	9.22	0.0176	0.0176	5.40	874
	I_1	8.89	0.0171	0.0173	5.65	755
	I_2	7.34	0.0172	0.0177	5.57	838
1942-43 .	I_0	5.46	0.01442	0.01852	8.66	569
	I_1	5.08	0.01431	0.01797	9.01	579
	I_2	4.47	0.01422	0.01790	8.69	604
1943-44 .	I_0	11.78	0.01515	0.01357	6.17	597
	I_1 . . .	9.49	0.01601	0.01417	6.18	564
	I_2	8.98	0.01644	0.01426	6.28	494

In all the three years mean parameter 'A' values were the highest in the weekly interval irrigation treatment and lowest in the critical moisture limit treatment. The mean daily growth rate values were the highest in the weekly interval treatment in the first two years. In the third year this treatment showed the lowest values. The difference between the mean daily growth rate values of ten days interval and critical soil moisture interval treatment was very small in the first year. In the second year the ten days interval treatment had higher value than critical soil moisture treatment. In the final year, however, the I_2 treatment exhibited higher mean daily growth rate than both the other two treatments of the experiment. The corresponding mean yield figures for the treatments given in last column of the Table indicate that the weekly interval irrigation treatment gave the highest yield in the crop years 1941-44 and 1943-44, while in the year 1942-43 it gave the lowest yield. In all the three years ten days interval treatment indicated yield level mid-way between the weekly and the critical moisture limit treatment.

The crop in the first year showed the least mean *Commercial Cane Sugar* per cent value with weekly interval irrigation and highest with critical soil moisture limit treatment. The differences in parameter 'b' values were very small. The lowest value was shown by ten days interval and highest by the critical soil moisture limit treatment. In the second season's growth the difference in the relative growth rate of the critical soil moisture treatment and ten days interval was negligible; weekly interval, with an appreciable difference, had the highest relative growth rate. Ten days interval showed the highest sugar content, the difference between the critical soil moisture stage and weekly interval treatments being again very small.

3. The results derived from the *Irrigation interval × Periods of planting x Varieties experiment* are summarized in Table XI as under:

TABLE XI

Exponential height growth curves

Treatments	Equation $H=Ae^{bt}$		S. E. of 'b'	Initial height	Final height	Mean daily growth rate
I_0 P_0 V_0	H=1·252e	0·0177t	±0·005287	8·15	240·68	0·0178
I_0 P_0 V_1	H=1·525e	0·0156t	± 0·000998	10·35	230·44	0·0158
I_0 P_1 V_0	H=5·43e	0·0171t	± 0·000609	10·20	240·47	0·0161
I_0 P_1 V_1	H=8·11e	0·0174t	± 0·000648	11·32	249·74	0·0158
I_1 P_0 V_0	H=0·981e	0·0169t	± 0·000563	9·09	193·46	0·0156
I_1 P_0 V_1	H=0·950e	0·0167t	± 0·000602	8·55	185·70	0·0157
I_1 P_1 V_0	H=5·54e	0·0172t	± 0·000594	9·89	189·05	0·0151
I_1 P_1 V_1	H=4·26e	0·0174t	± 0·001243	5·50	206·96	0·0184

A summary of the results is provided in Table XII of the text for comparison mean cane yield and *Commercial Cane Sugar* per cent values against each of the treatments have been shown. From a perusal of the data it is evident that a wide difference existed in the mean parameter 'A' values of the two treatments. In the mean daily growth rate, the difference was slight. Corresponding yield difference was in favour of the weekly interval treatment. On the other hand, mean *Commercial Cane Sugar* per cent value was higher for critical soil moisture limit treatment and so was the mean parameter 'b' value. Thus it appears possibly that mean parameter 'A' values influenced the cane yield and parameter 'b' values affected the *Commercial Cane Sugar* per cent values of the crop.

TABLE XII

Interrelated growth constants, yield and commercial cane sugar per cent values
(I_0—weekly interval ; I_1 —critical soil moisture limit interval)

Treatments	Mean parameter 'A' values	Mean daily growth rate	Mean parameter 'b' values	Mean C.C.S. per cent values	Mean yield md. per acre
I_0	4·079	0·016375	0·01695	5·96	813
I_1	2·933	0·016200	0·01705	6·74	556

GENERAL CONCLUSIONS

In the foregoing we have summarized the results of growth studies as modified by the external growth factor of irrigation which is under the control of the farmer. Increase or decrease in irrigation supply, conjointly with other habitat factors, shows its effect in terms of functional responses such as differences in growth by change of structure or by differences in accumulated reserve products. In our studies we have measured the growth response in terms of height and accumulation of reserve product in terms of commercial cane sugar.

Crowther [1944] working on cotton observed, 'Increase in height is a complex function...... Under the weather conditions of Sudan Geziria increase in node number, being the result of meristematic activity, was a function of nitrogen supply, whereas extension growth, as expressed in internode length was primarily a function of water supply. Increase in height is the product of the two.' Rege, Voghalkar, Wagle, Apte and Kulkarni [1943] also noticed that differential waterings influenced the internodal length of the cane crop. This was more marked in P O J 2878 than in *Pundia*. However, this effect was found to be short-lived and later formed internodes became shorter with 120 and 130 in. compared to 70 and 95 in. of irrigation supplied during the crop season. This, they attribute to the leaching of nitrates. Favourable effect of higher waterings on the increase in height was visible specially in P O J 2878 during the early phase, *i.e.* till August. Late growth, however, was more pronounced with smaller waterings which entirely masked the extra growth of the early phase.

In the preceding section we have reported data of eight experiments on the effect of irrigation intervals on growth values, cane yield and sugar reserves of the crop. In all cases weekly interval irrigation generally showed greater monthly growth values and larger cumulative growth of the crop than ten days or critical soil moisture limit interval treatments. In five out of eight trials the mean daily growth rate values were higher in the former compared to the latter two treatments. Parameter 'A' values of the exponential height growth curves were higher for weekly interval treatment in all the eight cases. As a result of better initial growth and mean daily growth rate, mean yield per acre of the weekly interval treatment was greater in five out of eight trials. Evidently observations on the development of the plant give fair indication of the likely performance with liberal water supply to the plants. Development in this case consists of initial rapidity of growth, cumulative growth in length and the daily growth rate of the stalks. Wardlaw [1944] points out that shoot apex must be regarded as a whole ; any particular region, e.g. the terminal meristem, a leaf or bud primordium cannot be treated as an isolated object but as an inseparable part of the integrated dynamic system. In the initial rapidity of growth of the shoot apex, as defined above, development of apical meristem and differentiation processes are involved. Apical meristem is the seat of possible future development. No sooner this development is completed differentiation process, which is the sum total of the morphological changes that are initiated with the cell enlargement and end with its death, comes to play its role and initiates tiller formation and differentiation of stelar system of the stalks. For maintaining a high level of cambial activity of apical meristem and to help the differentiation process at all stages of growth of the plants, liberal supply of water from the very beginning is indicated as essentianl, ot for the fact that water enters into the composition of the cell body but that it helps in the normal

absorption and translocation of nutrients and synthates into the regions of meristematic activity. Reed [1921] observed that rapid growth was associated with generally lower concentration of the sap in the shoots of trees such as walnuts, apricots and oranges, while slower growth was accompanied by higher sap concentration of these plants. The addition of water to the soil usually diminished the cell sap concentration and as such conduced to greater rapidity of growth. This further substantiates our conclusion stated above, namely, that for upkeep of a higher level of the activity of the apical meristem and the meristem concerned in differentiation for bud formation and more comprehensive development of the stelar system, liberal supply of water for the plants is essential to ensure high cane yield of the crop.

It is out of place and not within the scope of this paper to discuss the internal water balance of the plant in relation to growth and differentiation. But we have observed in Part I of this series Raheja, 1946 that when cellulose is being produced at the possible maximum rate under the effect of external environment, the simultaneous production of carbohydrates (sugars) is relatively slowed down and if certain conditions be imposed to reduce the rate of cellulose formation the rate of carbohydrate accumulation comparatively becomes more rapid. Clements' [1945] observations pertaining to the effect of decreased soil moisture on raising the carbohyderate level of the plant are very pertinent to this discussion. Out of eight trials in seven cases mean *Commercial Cane Sugar* per cent values were worked out. In six out of seven cases the mean C. C. S. per cent values were greater either for the critical soil moisture limit treatment or for ten days interval than weekly interval irrigation. Evidently reduced water supply to the plants retards the rate of cellulose formation and thereby enables them to accumulate more of carbohydrate. Further it is observed that parameter 'b' values for the weekly interval irrigation treatment in two out of eight cases only were greater than ten days or critical soil moisture limit treatments. Thus relative to the time (age) the critical soil moisture limit treatment exhibited more accumulation of sucrose than ten days or the weekly interval treatments. Das [1936] and Swezey and Wadsworth [1940], the former indirectly and the latter directly reached analogous conclusions that the degree of hydration of the tissues plays a very important role in regulation of the sugar synthesis in the plant. May be that under these conditions the diffusion of growth substances, which act as regulators of growth, is somewhat retarded so that shoot apex, consisting of terminal meristem, a leaf or bud primordium and differentiating region of the stelar system is unable to grow out and accumulate growth at the normal rate and sugars instead of being synthesized into cellulose are stored in the cane stem.

Summary

The paper summarizes the results of growth studies on sugarcane in relation to the controllable environmental factor of irrigation as applied on the basis of three intervals, namely, weekly, ten days and critical soil moisture limit treatments. The analyses of the data provide comparison of the cumulative growth in length, mean daily growth rate and exponential height growth curves in relation to yield and mean *Commercial Cane Sugar* per cent values of the crops. To indicate the effect of soil and weather conditions, chemical analysis of the soil types of the farm and the environmental conditions for the different years have been stated. The results may be summarized as under.

1. The cumulative growth in length was conditioned by the environmental factors in the different years. Favourable environment resulted in superior growth in the year 1942-43; it was less vigorous in the year 1941-42 and 1943-44 and was poor in the year 1940-41. The effect of early season, manifesting quick growth early in the season, was more potent than accumulation during grand growth period or maturation stage of the crop.

2. The cumulative growth in length is also conditioned by the irrigatoin supply to the crop. Maximum growth accumulation was shown by the weekly interval irrigation treatment. Regulation of irrigation interval on soil-moisture-plant-growth basis reduced the total accumulated growth to about that of ten days treatment.

3. Liberal irrigation supply (weekly irrigation) quickens early growth and mean daily growth rate of the crop. Both these factors tend to augment the yield of the crop.

4. The treatment of critical soil moisture limit for application of irrigation to the crop in majority of the cases conduced to greater accumulation of the *Commercial Cane Sugar* and higher relative growth rate of the crop. The cellulose formation, it appears, is limited by restricted water supply and hence more accumulation of sucrose takes place in the plants.

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ANALYSIS OF AGRICULTURAL YIELDS

I. MULTIPLE-FACTOR EXPERIMENT ON SPACINGS X NITROGEN DOSES X TIME OF APPLICATION OF NITROGEN

By P. C. Raheja, Sugarcane Specialist* and M. A. Azeez, Chemical Assistant, Sugarcane Research Scheme, N. W. F. P.

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(With one text figure)

SYSTEMATIC work on the agronomy of the sugarcane crop was begun in the year 1940 and a set of multiple-factor experiments with a view to study the interaction of factors in crop growth was planted. The results of one such experiment conducted for five years are now available. The objective of this experiment was to find out the optimum spacing required by the plant crop of sugarcane in the North-West Frontier Province. The sugarcane area of the province is located in the extreme north-westerly portion of India and is subject to recurring frosts in the winter season. It is clear that cane is cultivated beyond its natural habitat and at or near the geographical limit of possibility of sugarcane production. In fact over 92 per cent of the total cane area is confined to the Peshawar Valley which is more in the northerly direction than the 7 per cent planted in Bannu district of the province. The average growing season hardly exceeds about eight months. The crop seldom reaches full maturity and that too happens when the season in certain years rapidly cools and is frost free, which conditions hasten the maturing process with some resultant loss in cane yield. Contrasted with tropical or even with more favourable sub-tropical conditions for the crop, the climate is more unfavourable. Planting cannot be completed in autumn, for, the planted setts do not exhibit germination. The buds harden and germination in the spring is delayed. The seed cane is, therefore, required to be preserved by clamping through the frosty season for spring planting. When the weather is wet, there is disproportionate loss of seed cane in the clamp. Winter rains seldom fail. Thus a larger amount of seed material than required under normal conditions is preserved. Economy in seed material conduces to reduction in the cost of cultivation of cane. Spacing of rows at wider interspacing, consistent with high economic outturn per acre, offers one possibility of reducing the cost of cultivation per acre.

McDonald [1926] stated, 'Sugarcane differs from most other crops in that the desired yield is not produced directly from harvest, but from a manufacturing operation following the growth and harvesting of the plant. Yields depend on three more or less independent factors : first, on the size of the cane stalks (also number of cane stalks) or tonnage of cane ; second, on the amount of juice contained in the cane ; and third on the sucrose content of the juice.' He discussed the influence of Louisiana weather from 1890 to 1924 in relation to these factors and observed that March temperature exerted a large influence upon sugar yields in any given growing season. Sub normal rains through the grand growth period though slightly conduced to increase in sugar content but did not demonstrably increase the final total of sugar per acre from that crop. Other workers have discussed the effect of controllable environmental factors on the cane tonnage and acre sugar yield irrespective of the effect of the weather conditions in different years. As early as 1905 Dodds summarized the results of manurial experiments conducted in various countries. Rege compiled the findings in India from 1932 to 1939. Cliff's [1930] tests on various agricultural farms in North Bihar indicated a dose of 40 lb. nitrogen and 50 lb. P_2O_5 as giving an economic response in cane yield. These results have since been confirmed by Khanna [1937] which have further indicated that the application of full dose at planting is more economical than splitting it up into two and applying half at planting and half at earthing. Batham and Nigam [1936] while studying the effect of soil organic matter and nitrogen on cane observed

* Now Agronomist, Indian Agricultural Research Institute, New Delhi.

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a prolongation in the maturation period of cane crop with consequent increase in tonnage due to increased supply of both in the soil. Mathur and Haider [1940] from nitrogen fertilization studies concluded, ' The number of tillers produced increased with nitrogen given to the plant......Harvest data indicate, that, at all three levels of water, plants show a marked response to nitrogen application and that, at all the three levels of nitrogen......Nitrogen application leads to an increase in juice content.'

The effect of increasing nitrogen is to lower the sucrose and increase the reducing sugar percentage in juice. Purity of juice follows a similar course to that of sucrose. Rege *et al* [1940] concluded, 'Practically all the plant phases are favourably influenced by nitrogenous manuring.' Quick acting nitrogenous manures applied, at the rate of 15 lb. at planting time, were helpful for securing optimum germination. During tillering phase an application of 50 to 100 lb. proved effective. In the lower nitrogen series, the growth tended to cease earlier in grand growth period stage. Though higher applications increased the cane tonnage, they also reduced the concentration of sucrose in the expressed ju ce. Borden [1942] observed differential response to application of various doses of nitrogen applied differently. The initial application in higher concentration reacted more favourably towards an increase in tonnage than subsequent equal application after 10½ months. Commercial sugar yield was adversely affected by the higher dose application. Cornelison and Cooper [1941] had arrived at similar conclusions relating to nitrogen nutrition—time-of-application-of-nitrogen studies.

Dutt [1945] referring to results on optimum spacing in various countries states that closer planting is advantageous from economic point of view. He quotes Rosenfield extensively in support of the above conclusion. The economy results from fewer cultivation operations, reduced soil moisture loss, reduction in gaps due to defective germination, more stalks but less suckers per acre, additional frost protection, and less erosion under conditions of heavy precipitation. Crowther [1937] noticed that with close rather than wide spacing frequently, greater yields of cotton resulted with nitrogenous manuring.

Experimental

A preliminary experiment on three spacings × three doses of nitrogen × two time-of-application-of-nitrogen treatments was conducted in the year 1940-41. The results suggested elaboration of the experiment, the details of which are given in Table I.

Table I

Details of factors of the experiment

Spacing	Equivalent nitrogenous dose in compost	Time-of-application-of-nitrogen
S_0—close—2½ft.	N_0=50 lb. per acre	A_0=⅓ at planting : ⅓ at tillering : ⅓ at earthing up
S_1—medium—3ft.	N_1=100 lb. per acre	A_1=full dose at planting
S_2—wide—3½ ft.	N_2=150 lb. per acre	A_2=½ at planting : ½ at earthing up

Planting of seed cane was done in furrows opened with *desi* plough in clover (*Trifolium resupinatum*). The manure in the form of compost was applied in doses as indicated by the time-of-application-of-nitrogen treatments prior to the planting of the setts. Sub-samples out of the bulk compost were analyzed for nitrogen content a day or two prior to the application of manure. Setts after planting were covered with clover stubble and land was irrigated immediately after it. In treatment A_0 the dose of nitrog n to be applied at tillering phase was given after 1½ months of plan ing. Earthing up dose was applied plantwise prior to the irrigation applied for bringing the soil to condition for

the earthing up operation. The lay out of the experiment is shown in Table II. Every year cane was planted in two replications of the confounded design $(3)^3$ experiment. The characteristic features of the soil type, the rotation followed and the other field operations performed have already been described by the senior author [1946] in another connection. It may be mentioned that one border row on either side was maintained for each of the plots to ward off the border effect. The ultimate harvested plot size was 66 ft. × 15 ft. = 1/44th of an acre. Growth characters of the crop, *i.e.* relative growth rate tillering, thickness of cane stalks, etc. were recorded year after year and the data have been analyzed separately in another paper on the subject.

TABLE II

Multiple-factor experiment plan

Spacings × nitrogen doses × time-of-application-of-nitrogen

X2									X3									X1								
a_2	a_2	a_1	a_0	a_1	a_2	a_0	a_1	a_0	a_1	a_2	a_1	a_0	a_0	a_2	a_2	a_0	a_1	a_1	a_2	a_0	a_0	a_2	a_1	a_0	a_1	a_2
n_0	n_1	n_1	n_0	n_0	n_2	n_2	n_2	n_2	n_1	n_0	n_2	n_2	n_1	n_2	n_1	n_0	n_0	n_2	n_1	n_1	n_2	n_2	n_1	n_0	n_0	n_0
s_2	s_0	s_1	s_1	s_0	s_1	s_2	s_2	s_0	s_2	s_0	s_0	s_1	s_0	s_2	s_1	s_2	s_1	s_1	s_2	s_1	s_2	s_0	s_0	s_0	s_2	s_1
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
									Water channel																	
a_1	a_1	a_2	a_2	a_0	a_0	a_1	a_2	a_0	a_0	a_2	a_0	a_0	a_1	a_2	a_1	a_1	a_2	a_0	a_1	a_2	a_0	a_2	a_1	a_0	a_2	a_1
n_0	n_1	n_2	n_1	n_2	n_0	n_2	n_2	n_1	n_2	n_1	n_0	n_1	n_0	n_2	n_2	n_1	n_0	n_2	n_0	n_1	n_1	n_2	n_1	n_0	n_0	n_2
s_1	s_0	s_2	s_1	s_1	s_0	s_2	s_0	s_2	s_0	s_0	s_2	s_1	s_0	s_2	s_1	s_2	s_1	s_2	s_2	s_2	s_0	s_1	s_1	s_1	s_0	s_0
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Y1									Y3									Y2								

EFFECT OF ENVIRONMENT

The mean yields for the different years have been summarized in Table III as follows :

TABLE III

Cane and sugar yields in different years

Particulars	1941-42	1942-43	1943-44	1944-45	1945-46	S.E.
Cane yields—md. . . .	426·6	373·1	406·7	116·8	155·5	±117·4
C. C. S. per cent	9·06	8·68	9·71	8·61	8·48	± 0·759
C. C. S. yields—md. . . .	38·1	32·3	38·9	10·6	12·5	±11·34

It is evident that the results of cane yield are comparable in the first three years. In the subsequent years the crops suffered from rather acute shortage of water during the grand growth period. Differences in cane yield amongst the different years were indicated to be highly significant (P=0.01) (Table III) and this contributed to high standard error for the five years' results. Short irrigation supply during the crop seasons 1944-45 and 1945-46, however, did not conduce to high recovery from the cane crop. This is well-illustrated even by the comparison of first three years' results. In the

year 1942-43 the mean cane yield per acre was the lowest of the three seasons and yet *Commercial Cane Sugar* per cent value of the crop was not high but low. Evidently restricted irrigation supply did not produce an evident accumulating effect on sugar per cent on cane. These differences amongst the treatments were significant (P=0.01). Thus, besides irrigation, other seasonal factors were more potent in modifying the content of sucrose in cane. Koenigs [1930] established equations between moisture and temperature factors and sucrose of the cane. The expression derived by him was R=Ce —(ah+bt), where R=sucrose content to be determined, h and t moisture and temperature figures expressed in in. of water and degrees of centigrade respectively, 'e' the base of natural longrithm. Das [1931] concluded that cool and dry weather conduced to excellent juice quality. As the weather tended to be hot and wet the sucrose content in juice decreased. Mathur [1940] observed, 'It is interesting to note that the rythum of climate and cane growth and sucrose formation take a similar course'. Further on, he pointed out that the development of sucrose exhibits three phases. The first phase extends from October to December. During this phase sucrose accumulation per week takes place at a more rapid rate than the subsequent two phases. The second phase of sucrose development is completed in the end of February. In the third phase beginning with early March greater accumulation of glucose than sucrose was observed. The authors have noted that sucrose content in cane consistently increases right from its early stages till, the time frosts intervene. This is well illustrated by data presented in Fig. 1. The first fall of frosts occurs about the 15th November every year. Depending upon the severity of the frosts, Khan and Raheja [1943] have shown, that the development of sucrose in cane is arrested or a decrease in content of sucrose in juice occurs. To us, it appears, in Peshawar valley principally the severity of frosts determines the juice quality. It was noticed that the crop seasons 1941-42 and 1943-44 were frost free. The worst effect of frost was noticed in the year 1945-46. Continuously for over $2\frac{1}{2}$ weeks day after day frosts (very low minimum temperatures touching 25°F) occured. By these frost bites, the foliage were killed and instead of the sugar accumulating in the cane stalk, deterioration in juice quality was observed.

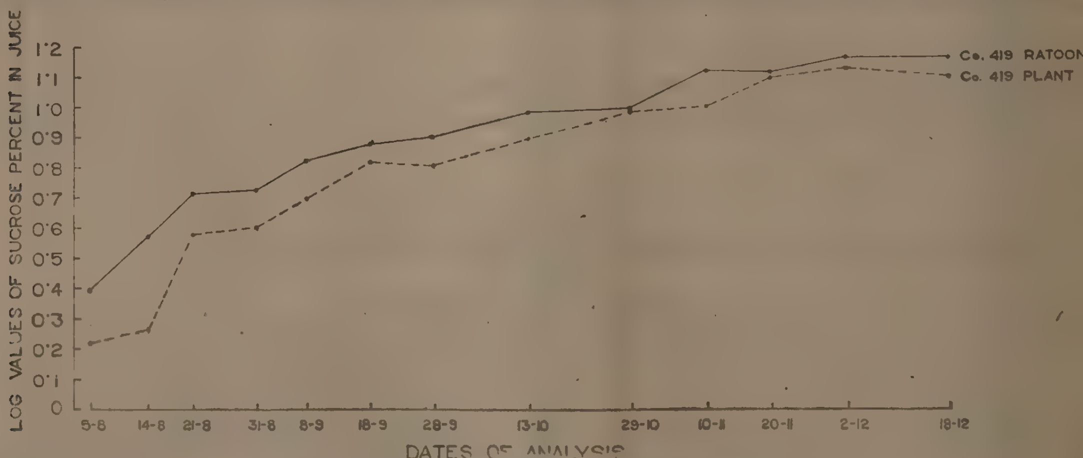

FIG. 1. Course of accumulation sucrose in cane crop.

Acre sugar yields summarized in the above Table have been derived by multiplying the plot yields and the respective sucrose per cent values of cane from those plots. They are thus the mean sugar yields per acre. It is observed, that amongst the various years, the differences were highly significant. The factors responsible for wide differences have already been stated. They principally affected the cane yield and thus the sugar yield per acre.

Influence of spacing

Wider spacing of rows conduces to economy of seed material and provides greater working facility in between the rows as given in Table IV.

TABLE IV

Cane and sugar yields in relation to spacing

Particulars	Close 2½ ft.	Medium 3 ft.	Wide 3½ ft.	S.E.
Cane yield—md.	309·6	297·0	282·1	±117·4
C. C. S. per cent	8·81	8·92	9·01	± 0·759
C. C. S. yield—md.	28·4	27·0	25·4	± 11·34

Wider spacing exposes the plants individually to more light and gives greater scope of tillering to each of the plants. In spite of these advantages it was noticed that except in the year 1942-43 when yield with wide spacings was a few lb. extra, in all other years spacing of rows at wider distances resulted in lowering of cane yield. In the following year *i.e.* 1943-44 the differences in yield between the close and wide spacing was significant. As already pointed out the yield of the trials was very much depressed in the years 1944-45 and 1945-46. The results thus collectively have shown ve y high standard error and as such the differences indicated are not significant. But the differences in cane yield clearly point to the advantage of closer spacing in between the rows. Even economically close spacing is preferable to wide or even medium spacings.

The results of commercial cane sugar per cent values indicate a slight improvement with wide spacing. The differences, however, were not significant for any of the years and were not consistently indicated for all the five years in favour of wide spacing. The cane yield differences were sufficiently in favour of close and medium spacing to mask the effect of increase in sugar per cent in cane. During the year 1943-44 the sugar yield per acre differences were significant between wide and close or wide and medium spacing in between the rows. Mean difference over five years was as great as 2 md. of sugar per acre between the close and wide spacing. For plant crop, it appears, from sugar yield point of view, the planting of canes at wide spacing does not appear economical compared to close or medium spacing in between the lines of the cane crop.

RESPONSE TO NITROGEN

Nitrogen in the experiment was applied in the form of compost on the basis of its analysis. The response has not been uniform in the different years. The conditions of water supply in the last two years being abnormal these results have been omitted out of discussion. An actual depression in cane yield was manifested in the first season by double and treble doses of nitrogen over the single dose application (Table V).

TABLE V

Cane yield in maunds in various years with different doses of nitrogen

Nitrogen in lb. per acre	Years of experiments			Remarks
	1941-42	1942-43	1943-44	
50 lb	449·2	336·2	374·0	* indicates significant results at P=0·05
100 lb	402·3	376·0	409·0	....
150 lb	424·0	407·2	436·7	....
Mean	426·6	373	406·0	....
Standard error	±97·9	±73·1*	±79·8*	....

In the two subsequent years *i.e.* 1942-43 and 1943-44 significant increasing responses in cane yield were revealed by the crops. Thus in two out of three normal years, the application of nitrogen exhibited significant yield responses. Willcox [1945] cites a case of manuring grapes with nitrogen and potash conducted by Wellington and Collison [1943] in New York State wherein a depression curve of grapes yield was revealed with increasing doses of nitrogen when potash was applied. 'Corrective influence of K on the depressive effect of an excess of N was evident.' He, thus, ascribes the yield depression effect of fertilizer to nutrition unbalance in the field test. He [1945] interpreted the results of Carolus's [1944] experiments on potato tubers wherein depression effect of nitrogen was manifested in an N. P. K. experiment. He reformed the depression curves and drew the same inference that nutrition unbalance was the cause of depression effect in the field test. It may be that, this phenomenon manifested itself in the year 1941-42 in our experiment. In another connection Willcox [1944] says that when tests with plant nutrients are carried out no out side interference with the reaction between the soil and the plants may be apprehended even though the soil variability may be great. 'The common sense thing to do is simply to accept the average yields from the treatments at their face values and graph them on the standard yield diagram, where their degrees of abnormality or aberrancy will be disclosed'. Further he states on the other hand, where the object is to determine the relative yielding abilities of different varieties soil variability represents an outside interference and in the absence of correct information may properly be dealt with by statistical methods. Since normal responses were obtained in two out of three experiments, standard response curves of nitrogen application from the form of response curve [Crowth and Yates 1941] were derived by the equation.

$$Y = Yo + d(1-10^{-K_x})$$

'Where Y is the yield with a fertilizer dressing of X cwt. of nitrogen, Y_0 the yield with no fertilizer, d the limiting response and K a value assumed to be constant for nitrogen in this case.'

The results are shown in Table VI as under:

TABLE VI

Increment in yield response in values and net returns

Depressing of nitrogen	Cost of dressing	1942-43 Cane yield response	Response in value	Net return	1943-44 Cane yield response	Response in value	Net return
lb.	Rs.	md.	Rs.	Rs.	md.	Rs.	Rs.
50	10·4	50·8	22·2	11·8	43·75	19·1	8·7
100	20·8	90·6	39·6	18·8	78·75	34·5	13·7
150	31·2	121·8	53·3	22·1	106·75	46·7	15·5
200	41·6	146·3	64·0	22·4	129·75	56·8	15·2

The normal price of factory cane in the pre-war years ranged from Rs. -/6/- to Rs. -/7/- per maund. Basing our calculations on Rs. -/7/- per md. of cane the responses in values have been indicated. In normal times compost, having 0·6 per cent nitrogen in it is available at Rs. 2 per cartload which approximately weighs twenty maunds. Determining on this basis, the cost of compost works out to Rs. -/3/4 per lb. of nitrogen. From both these experiments it is indicated that the best response in terms of net return is shown by a dose of 150 lb. nitrogen. A slightly decreased response in net return is indicated at 200 lb. of nitrogen per acre. The statement does not merely indicate the economic aspect. More than that, it indicates, the net economic advantage to be obtained by application of nitrogen up to 150 lb. per acre.

Commercial recoverable cane sugar values for all the years have been summarized in Table VII. The differences were significant amongst the treatments for the first two years. For the subsequent years results were not significant.

TABLE VII

Commercial recoverable cane sugar in various years with different doses of nitrogen

Nitrogen in lb. per acre	Per cent value in different years					General C.C.S. per cent	Mean C.C.S. yield. md.
	1941-42	1942-43	1943-44	1944-45	1945-46		
50	9·49	8·60	9·54	8·79	8·51	8·98	25·9
100	9·39	8·56	9·73	8·24	8·16	8·82	26·5
150	8·30	8·90	9·89	8·80	8·76	8·93	27·5
Mean . . .	9·06	8·69	9·72	8·61	8·48	8·91	..
Standard error .	±1·167	±0·942	±0·585	±1·20	±0·377	±0·759	..

It will be observed that in all the years except 1943-44 with 100 lb. dose there was a decrease in commercial cane sugar per cent value. But with an increased dose there was indicated an increase in ccs. per cent values in four out of five cases. Thus the mean values for all the years indicated the lowest c.c.s. per cent value for 100 lb. dose.

Das [1936] while dealing with the subject of juice quality stated that heavy application of nitrogen specially in the second season appears to lower the quality of juice. Our results indicate that with 100 lb. dose though the sugar content in cane is decreased, with 150 lb. dose an increase was indicated in majority of the years. Rege [1944], however, observed that delaying of harvest did not help in the formation of maximum sucrose with higher manuring. It is significant to note that when yield tends to correspond to an economic optimum value of nitrogen, an increase in sucrose content is manifested. It appears 'Tamman's Principle' operates here also [Tamman 1892, 1895]. Two opposed processes, the formation of plant body out of the environment and energy constant of the habitat [Leak—1943] interact, resulting either in higher tonnage or greater concentration of sucrose. So long as the carbohydrates are required for purposes of growth (increasing the tonnage) the accumulation of sucrose can only take place at a retarded pace, but once energy constant of the habitat limits the growth greater concentration of sucrose in sap results. With 100 lb. dose the processes of growth remain active and tonnage tends to accumulate more than sucrose. But with application of 150 lb. dose of nitrogen not only the optimum requirements for increase in tonnage are satisfied but juice becomes richer in sucrose. The sugar per acre yield made a difference of 0·6 md. only with the first 50 lb. increment of nitrogen but with a subsequent increase of 50 lb. an extra quantity of 1·0 md. of sugar was manifested by the crop.

EFFECTIVENESS OF THE TIME-OF-APPLICATION-OF-NITROGEN

The senior author [1946, 1948] has fully discussed the implications of logistic principle of plant growth in sugarcane. As such, it appears plausible to presume that time of application of nitrogen ought to influence both the initial potential of growth and the relative rate of growth of the crop. In Table VIII are given the data of the experiment*.

* For reference to treatments see Table I.

TABLE VIII

Effect of time-of-application-of-nitrogen on cane yield : Commercial cane sugar per cent values and sugar yield per acre

Year of experiment	Cane yield—maunds			C.C.S. per cent			C.C.S. yield-maunds		
	A_0	A_1	A_2	A_0	A_1	A_2	A_0	A_1	A_2
1941-42 .	421	432	423	9·31	9·38	8·96	36·9	43·9	33·7
1942-43 .	348	397	379	9·03	8·33	8·68	31·7	32·6	33·1
1943-44 .	426	396	397	9·66	9·56	9·92	39·9	37·8	39·1
1944-45 .	113	125	112	8·63	8·82	8·37	10·6	11·7	9·5
1945-46 .	143	146	162	8·71	8·70	8·14	12·4	12·1	13·1
Mean . .	290	299	295	9·07	8·96	8·81	26·3	27·6	25·7

Results indicate, that every time the same treatment had not exhibited its effectiveness in increasing the cane yield, commercial cane sugar per cent value or sugar yield of the crop. But in most cases, full dose application of nitrogen at germination (A_1) enhanced the cane yield of the crop. This also is indicated by the general mean difference amongst the treatments. Full dose application (A_1) gave the maximum and two split up doses (A_2) the minimum sugar yield per acre. These indications require further confirmation under better conditions of water supply.

SUMMARY

A multiple-factor experiment on *spacings* × *nitrogen levels* × *time-of-application-of-nitrogen* has been described. The experiments extending over five years were conducted on plant crop to work out its local requirements. The spacing generally practiced in the North-West Frontier Province is 3 ft. interspace in between the rows. Spacings of 2½ ft. (S_0) and 3¾ ft. (S_2) were tested against it. Generally, compost is applied to the maximum extent of eight cartloads (160 md.) in three split up doses, at germination, tillering and grand period before earthing up stages. In order to standardize the schedule of nitrogenous top dressing compost containing 50 (N_0), 100(N_1) and 150(N_2) lb. nitrogen was applied in three sets of treatments, namely, applied in full dose at planting (A_1), two split up doses *i.e.*, half at planting and half at earthing up (A_2) and local practice of applying in three split up doses (A_0) *i.e.*, one-third at planting, one-third at tillering phase and the remaining one-third at earthing up of the crop. The results may be summarized as under :

1. Crop yields were comparable in the first three years. In the subsequent two years the cane yields were abnormally depressed due to acute shortage of water supply in the grand period stage of the crop. Thus differences in cane yield amongst the various years were significant (P=0·01). Short irrigation supply in the two latter years did not conduce to high sugar recovery from cane crop. Principally the severity of the frosts determined the juice quality at harvest.

2. Closer spacing on the whole resulted in higher yield and thus higher yield of sugar from the crop in spite of the higher concentration of sucrose in juice by wider spacing of the crop.

3. In three years normal yields of cane were realized. In two out of these three years, increased responses in cane yield to double and treble doses were indicated by the results. In both cases, the differences in yields were statistically significant (P=0·05). Yield response curves of two years' results showed the highest net return from cane yield with 150 lb. nitrogen dose application. At

this level of nitrogen fertilization, instead of the concentration of sucrose being further reduced, an increase in sugar content was observed. Thus highest sugar yield response was indicated with 150 lb. nitrogen application.

4. Full dose application of nitrogen at planting not only showed higher cane yield but also high sugar yield per acre. Economically it is cheaper to apply in one than in two or three split up doses.

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THE TIME OF PLANTING SUGARCANE IN RELATION TO VARIETIES AND MANURING

By S. B. Singh, M.Sc., Ph.D. (Cantab.), Director, Sugarcane Research Station, Shahjahanpur* and Ram Krishan, M.Sc., Farm Superintendent (Senior Agronomical Assistant), Main Sugarcane Research Station, Shahjahanpur

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(With one text figure)

ONE of the most important factors affecting the yield of cane is the time of its planting. A deviation on either side from the optimum planting period which in the plains of the United Provinces varies from mid January to mid March, affects germination, tillering and final yield of the crop. Planting very early in the season when the temperatures are below optimum results in a delayed germination and consequently in a greater termite attack and destruction of buds. Planting late in the season results in a quicker germination but the germinated shoots with poorly developed roots are not able to stand the hot and dry winds which begin to blow soon after germination. These shoots, either die out or grow very slowly and throw out comparatively very few tillers causing serious loss in yield.

The extent of loss in yield due to late planting is not similar in all varieties of sugarcane. There is a significant interaction between varieties and the time of planting. Table I shows the comparative results of seven experiments with different varieties and times of planting. The varieties tried in these experiments are the most common varieties of the province, Co. 385 and Co. 313 representing the early group, Co. 312 and Co. 421 the medium and Co. 331, the late group.

TABLE I

Yield of cane per acre in maunds in different dates of planting

Serial No.	Year of trial (No. of years)	Place of trial	Variety	Date of planting					Decrease in yield in April over March planting		Critical difference maunds per acre
				December	January	February	March	April	md.	Per cent	Date of planting
1	1935-36	Main Sugarcane Research Station, Shahjahanpur	Co. 313	..	824	802	697	412	285	40·9	156 (P=·01)
2	1936-37	Main Sugarcane Research Station, Shahjahanpur	Co. 313	..	737	679	508	155	353	69·5	Date of planting 88(P=0·01)
3	1937-38	Main Sugarcane Research Station, Shahjahanpur	Co. 385	..	619	546	615	399	216	35·1	Date of planting 91(P=·01)
			Co. 312	..	778	768	805	697	108	13·4	Varieties 42 (P=·01)
			Co. 331	..	668	624	700	570	130	18·6	Date of planting × Varieties, 84 (P=·05)
						Mean					
					687	646	707	555			

* Now Director of Agriculture, U. P., Lucknow.

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TABLE 1—*contd.*

Yield of cane per acre in maunds in different dates of planting—contd.

Serial No.	Years of trial (No. of years)	Place of trial	Variety	Date of planting					Decrease in yied in April over March planting		Critical difference maunds per acre
				December	January	February	March	April	md.	Per cent	Date of planting
4	1937-38	Sugarcane Research Station, Muzaffarnagar	Co. 385	..	..	..	499	369	130	26·1	Date of planting 42 (P=·01)
			Co. 312	..	..	..	772	713	59	7·6	
			Co. 421	..	..	..	788	688	100	12·7	Varieties 121 (P=0·01)
			Mean				686	590			
5	1939-42	Main Sugarcane Research Station, Shahjahanpur	Co. 313	..	..	608	670	394	276	41·2	Date of planting 33 (P=·05)
			Co. 421	..	..	740	698	524	174	24·9	Varieties 33 (P=0·05)
			Co. 331	..	..	675	705	517	188	26·7	Date of planting × varieties 57 (P=·05)
			Mean			674	691	478	..	..	
6	1944-45	Main Sugarcane Research Station, Shahjahanpur	Co. 421	671	720	708	..	455	..	..	Date of planting 107 (P=·01)
7	1945-46	Main Sugarcane Research Station, Shahjahanpur	Co. 421	503	689	..	755	337	..	..	Date of planting 112 (P=·01)

A perusal of data indicate that:

1. The effect of early planting (earlier than say mid-January) is not so deleterious as might be expected from the poor germination in these crops. The effect of late (April) planting, on the other hand, is very harmful and results in a decrease of 100 to 300 maunds cane per acre or 10 to 40 per cent. loss in yield as compared to the optimum time of planting. These results are explained by the fact that the low germination in the early planted crop is more or less compensated by increased tillering whereas in late planting, the germinated shoot gets a severe set back from hot and dry winds and both tillering and yield at harvest are greatly reduced. Table II below illustrates the variations observed in germination per cent., tillers and final yield in relation to dates of planting in the case of three experiments conducted at Shahjahanpur.

TABLE II

Showing germination, tillers and final cane yields per acre in the different dates of planting

Experiment No. (Year)	Date of planting	Variety	Germination per cent	Tillers	Yield of cane in md.
1. (1944-45)	December 14	..	21·3	58501	671
	January 18	..	25·2	65292	720
	February 24	Co. 421	27·9	63653	708
	April 10	..	41·5	47540	455
2. (1943-44)	November	..	18·9	33395	430
	December	..	25·2	36622	472
	January	Co. 385	28·9	38558	496
	February	..	26·3	37429	412
	March	..	24·1	28394	406
	April	..	14·1	22102	225
3. (1939-41)	February	Co. 313	51·0	104413	698
		Co. 421	55·8	74135	789
		Co. 331	41·9	101297	731
	March	Co. 313	60·0	109771	731
		Co. 421	62·1	66274	749
		Co. 331	54·9	98049	774
	April	Co. 313	48·6	61393	538
		Co. 421	53·2	35920	635
		Co. 331	51·3	59218	607

Late (April) planting affects the yield of both the early varieties to a greater extent than that of the medium and late ripening varieties used in these experiments. The data (Table I and Figure I) show that the loss in tonnage in Co. 385 and Co. 313 is greater than in Co. 312, Co. 421 and Co. 331. The loss in yield has also been expressed as a percentage of the March planted crop. The average loss in experiment 5 (Table I carried out for 3 years is 41·2 per cent. in Co. 313, 24·9 per cent. in Co. 421 and 26·7 per cent. in Co. 331. Where late planting is unavoidable it would therefore be better not to sow the early varieties *viz.* Co. 385, and Co. 313. This point is of considerable importance where the local agricultural practice, the pressure on land or the prices of gur or cane induce the cultivators to plant their cane after wheat, gram or arhar (Cajanus).

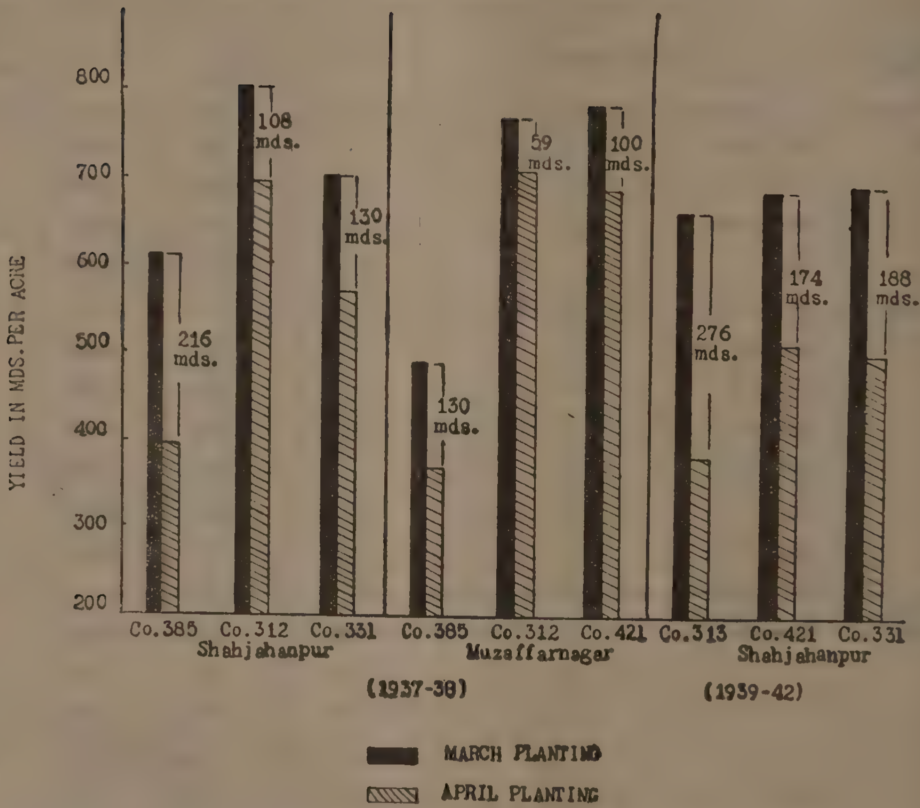

Fig. 1. Showing decrease in yield of cane (mds. per acre) due to late (April) planting over March planting.

Time of planting and nitrogenous manuring

In experiment 5 of Table I, the varieties and the dates of planting were tried at 3 levels of manuring 0,100 and 200 lb. N. per acre applied in the form of sulphate of ammonia and 3 levels of irrigation, which need not concern us for our present purpose. The layout adopted was Yate's 9 × 9 half-plaid square. The average figures of 3 years' trial (Table III) show that the percentage loss in yield due to late planting varies with different varieties and levels of nitrogen application. This loss, both absolute and calculated as percentage of March planted crop is greatest in Co. 313 an early variety and least in Co. 421 and Co. 331 which are medium and late ripening varieties respectively. The data also reveal that the percentage loss in yield due to late planting is greatest under unmanured control and least in 200 lb. N. applications per acre. The differences between 0 lb. N. and 100 lb. N. per acre are negligible except in Co. 331 where the loss in 100 lb. N. is 21·4 per cent as compared to 35·5 per cent. in the unmanured control.

TABLE III

Showing mean yields of cane in maunds per acre in different dates of planting under varying nitrogenous manuring

Varieties	Nitrogen dose per acre	Date of planting			Decrease in yield of cane in April over March planting	
		February	March	April	Mds.	Per cent
Co. 313	0 lb. N	526	576	325	251	43·6
	100 lb. N	689	715	403	312	43·6
	200 lb. N	609	719	456	263	36·5
Co. 421	0 lb. N	598	605	425	180	29·7
	100 lb. N	804	739	512	227	30·7
	200 lb. N	817	750	634	116	15·5
Co. 331	0 lb. N	606	574	370	204	35·5
	100 lb. N	751	732	575	157	21·4
	200 lb. N	667	809	607	202	24·9

Table IV gives the responses of varieties to nitrogen applications in different planting dates. It is seen that:

1. In February planting the best response is shown by Co. 421.
2. In the March and April plantings the best response is shown by Co. 331 and least response by Co. 313, an early variety.

TABLE IV

Response of varieties to nitrogenous applications in different planting dates (Increased yield in maunds per acre over the unmanured control)

Nitrogen dose per acre	Varieties	Response to N applications in md. per acre — Date of planting (—)			Difference in response (md.) per acre to N in April planting over March planting
		February	March	April	
100 lb. N	Co. 313	163	139	78	—61
	Co. 421	206	134	87	—47
	Co. 331	145	158	205	+47
200 lb. N	Co. 313	83	143	131	—12
	Co. 421	219	145	209	+64
	Co. 331	61	235	237	+2

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The differential response of varieties to manuring thus shows a striking and significant* interaction with dates of planting. Whereas Co. 313 and Co. 421 more or less consistently show a falling response to nitrogen with delay in planting, in Co. 331 the response appears to increase with later plantings. This differential behaviour of varieties finds some explanation in another experiment on the uptake of nitrogen in three varieties manured at 100 lb. nitrogen per acre (Table V). It is seen that Co. 385 (an early variety like Co. 313) and Co. 421 show a decreasing and Co. 331 a slightly increasing absorption of nitrogen from the soil with delay in planting dates from January to March.

TABLE V

Showing uptake of nitrogen in lb. per acre from the soil by different varieties planted at different periods

Time of planting	Varieties		
	Co. 385	C. 421	Co. 331
January	59·6	70·6	77·1
February	56·0	73·9	76·0
March	50·4	64·9	78·5

The losses in crop yield due to late planting occur in two ways: firstly the yield of cane is adversely affected by late planting due to the adverse effect of weather on germinated shoots and tillering; secondly in the cases of Co. 313 and Co. 421 there is a reduction in the response to manurial applications. In the case of Co. 331, the response to manure is slightly better in late planted crop but it is not sufficient to fully compensate the loss due to late planting.

The varieties tested above fall into three categories: early, medium and late. It is possible that the differential behaviour shown by them applies to the classes which they represent. This needs further confirmation with other varieties.

SUMMARY

1. The effect of early planting (earlier than the optimum) on yield is not so deleterious as might be expected from the low germination obtained in these crops. The effect of late planting on the other hand is very harmful and results in a loss of 10 to 40 per cent or 100 to 300 mds. decrease in the yield of cane per acre over the optimum time of planting. The results are explained by the fact that the low germination in the early planted crop is to a great extent compensated by increased tillering, while in the late planted crop both the tillering and growth are poor.

2. There exists a significant interaction between the time of planting and varieties. While all the varieties experimented upon give reduced yields with later planting dates, the losses are greater in Co. 385 and Co. 313 and less in Co. 312, Co. 421 and Co. 331. In any programme of planting which is spread over a long period, therefore, the varietal sequence in planting should be an important consideration.

3. The differential response of varieties to nitrogen varies with the planting dates. While Co. 313 and Co. 421 more or less consistently show a falling response to nitrogen with delay in planting, in Co. 331, a late variety, the response appears to increase slightly with later plantings.

4. While there are indications that the inference drawn above in respect of the different varieties are applicable to the classes of varieties which they represent, confirmatory experiments with other varieties of the early, mid-season and late classes are desirable.

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* Observed 'F' for variance due to varieties x nitrogen x date of planting being 3·82 while the 5 per cent value is 2·59. The full table of analysis of variance has been omitted to save space.

EFFECT OF SOWING TIME ON GROWTH AND DEVELOPMENT OF JUTE. II

By J. C. Sen Gupta, Nirad Kumar Sen and D. K. Mukherjee, Presidency College, Calcutta

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Sen Gupta and Sen [Part I] observed that as the sowing of jute was delayed from the end of March to the end of June, the vegetative period was progressively reduced. Rate of growth in height increased with the lateness of sowing and within certain range of sowing dates, the heights reached at the time of fruiting were almost similar. However, as the sowing was delayed lesser number of nodes and leaves were produced, branching was reduced and shedding of leaves from the base hastened.

In this experiment the plants were grown in field plots in place of earthenware pots, and besides height, number of nodes, time of flowering and fruiting, dry weight and water content at different stages were recorded. Attempts have also been made to correlate growth and development with meteorological factors to which the plants are exposed at different stages.

Experimental

The experiment was conducted with two species of jute, *Corchorus capsularis* (D 154) and *C. olitorius* (Chinsura green) in the experimental garden of the Presidency College, Calcutta. Plants were grown in plots with two replicates for each treatment. The plots were of equal size 3 ft. × 3 ft. laid in two parallel rows, thoroughly dug and manured with cowdung. Duplicates of each treatment were distributed in the field. Seeds were sown in five lines, each line about six inches apart. As the seedlings developed, they were gradually thinned out keeping nine to ten plants in each line at a distance of about three to four inches from one another.

At an interval of 30 days, four sowings of *C. capsularis* on 1 April, 1 May 31 May and 30 June and three of *C. olitorius* on 1 May, 31 May and 30 June were done. The plots were regularly watered when there was no rain.

As the plants developed, samples were taken out in the morning between 7-8 A.M. at an interval of 30 days, to record monthly growth, avoiding border-line plants. Every possible care was taken to dig out the root system as fully as possible. The plants were labelled, brought to the laboratory and the underground parts were thoroughly washed with a brush to remove the soil particles before weighing. For recording dates of flowering and fruiting six plants selected at random from each plot were labelled and regularly observed in the afternoon.

The following records were kept of the growth and development of the different sowings of jute. The results have been expressed as the mean of six plants for height, number of nodes, dry weight, and water content; and of twelve plants for flowering, fruiting and the circumference at the base of the stem.

Height. Height was measured with a centimetre scale from the level of the soil to the stem tip.

Number of nodes. All the nodes were counted, including the cotyledonary node, but excluding three to five undeveloped nodes in the apical rosette.

Dry weight. The sampled plants were chopped and separately dried in a thermostat at 80-85°C. for two to five days, and finally at 100° C. for four to six hours.

Water content. The percentage of water in terms of dry-weight was calculated from the difference of fresh weight and dry weight.

Time of flowering. The mean date of initiation of first flower dud in the plants was taken as date of flowering.

Time of fruiting. The mean date of initiation of first fruit was taken as the date of fruiting.

Records for the height, number of nodes, fresh weight, and dry weight were taken till the initiation of fruits, though growth continued after this.

The circumference at the base of stem. This was measured in cm. by means of a thread on 30 October when all the plants have fruited.

Meteorological data. Records of maximum and minimum temperatures, rainfall, relative humidity, total hours of bright sunshine and the total hours of day length have been taken from the local observatory.

RESULTS

Time of flowering and fruiting. In all the sowings of *C. capsularis*, flower bud initiated from the middle of August to the middle of September (Table I). With a difference of sowing time of 90 days, flowering was delayed by about 30 days and fruiting by 12 days, the vegetative period was progressively shortened from 137 days to 75 days. In the last sowing the interval between the time of initiation of buds and fruits was also very short. In *C. olitorius* flower buds initiated from the end of August to the beginning of September, there being a difference of 12 days in flowering and five days in fruiting, when the sowing was delayed by 60 days. The vegetative period was gradually shortened from 119 days to 70 days in sowings from 1 May to 30 June. Number of days required from flowering to fruiting was also progressively lesser with the lateness of sowing.

TABLE I

Time of flowering and fruiting

Date of sowing	*C. capsularis*				*C. olitorius*			
	Date of flowering	Length of vegetative period	Date of fruiting	Time from flowering to fruiting	Date of flowering	Length of vegetative period	Date of fruiting	Time from flowering to fruiting
April 1 .	16 Aug.	137 days	12 Sept.	26 days	..	..	..	..
May 1 .	17 Aug.	107 days	13 Sept.	27 days	28 Aug.	119 days	12 Sept.	14 days
May 31 .	26 Aug.	87 days	15 Sept.	20 days	29 Aug.	89 days	10 Sept.	11 days
June 30 .	13 Sept.	74 days	24 Sept.	10 days	9 Sept.	70 days	17 Sept.	8 days

TABLE II

Species	Dates of sowing	Dry weight in gm. Days after sowing						Monthly increase in dry weight						
		30	60	90	120	150	180	0-30th Day	30 to 60th Day	60 to 90th Day	90 to 120th Day	120 to 150th Day	150 to 180th Day	Average increase in dry wt. per day
C. capsularis	1 April .	1·61	17·78	58·59	93·33	150·20	159·08	1·60	16·17	40·81	34·74	56·87	8·88	0·8887
	1 May .	2·14	30·07	89·18	111·18	..	..	2·13	27·93	59·11	22·00	...	..	0·926
	31 May .	1·22	14·99	45·95	50·42	..	..	1·21	13·77	30·96	4·47	..	..	0·4201
	30 June	0·88	7·15	14·77	24·91	..	..	0·87	6·27	7·62	10·14	..	..	0·2075
C. olitorius	1 May .	2·84	34·13	129·00	144·33	..	..	2·83	31·29	94·87	15·33	..	..	1·2027
	31 May .	1·27	15·07	56·30	57·28	..	..	1·26	13·80	41·28	0·98	..	..	0·4775
	30 June	0·40	6·18	21·53	23·35	..	..	0·39	5·78	15·35	1·82	..	..	0·1948

In both the species as the sowing was delayed from 1 May, the dry weight at all the stages of deve-opment of the plants, gradually decreased. The growth curves were sigmoid, but gradually flattened vith the lateness of sowing, and in the last sowing of *C. capsularis* it was almost a straight one. In *'. capsularis* when the sowing was delayed by a month, the level of dry weight maintained was about ialf of that in the previous sowing, and this is true in all the stages of growth recorded. In *C. olitorius*, he effect was more pronounced, the level being less than half throughout the experiment. In April sowing of *C. capsularis* the dry weights were always lesser than those in 1 May sowing, out those plants ultimately accumulated more dry matter due to their prolonged vegetative period. The dry weights of 1 April sowings were, however, at higher levels than 31 May sowing, and on the 120th day became double of it.

In all the sowings of both the species, the highest growth rate recorded was between 30-60th day, and among all the sowings the maximum growth rate was observed in 1 May sowing of *C. capsularis*, and in 30 June sowing of *C. olitorius*. In the reproductive period, though considerable dry matter accumulates, the rate of growth is very slow. The average increase in dry weight in gram per day, calculated for 0-120th day by dividing the total increase in the dry weight from the initial dry weight of the seed, by the time in day required to attain it, gradually became slower with the lateness of sowing. In 1 April sowing of *C. capsularis* the average increase was, however, lower than that in 1 May sowing, but higher than that in 31 May sowing, being 0·7777 calculated on the basis of longer vegetative period of 180 days.

The monthly accumulation of dry matter was not at all uniform in the different treatments as well as in the different stages of growth of the same treatment. In *C. capsularis* accumulation of dry matter in each month varied from 0·9 to 59·1 gm. and in *C. olitorius* from 0·4 to 94·8 gm. The curves of dry weight accumulation are parabolic in nature. In the last sowing of *C. Capsularis*, however, the monthly accumulation of dry matter was at a much slower pace, and continued to increase in all stages of growth.

Water content

TABLE III

Water content expressed as percentage of dry weight

Species	Date of sowing	Days after sowing: 30	60	90	120	150	180
C. capsularis	April 1	522·37	375·68	354·25	335·83	377·63	332·55
	May 1	463·19	505·36	387·21	361·29	..	..
	May 31	767·63	426·21	406·30	338·57	..	..
	June 30	576·07	516·45	366·40	260·70	..	..
C. olitorius	May 1	512·65	450·32	344·96	446·83	..	..
	May 31	813·72	466·42	353·78	217·70	..	..
	June 30	650·38	316·31	324·46	283·81	..	..

It is seen that except for a rise of water content from 120th to 150th day in the sowing of 1 April and from 30th to 60th day in the sowing of 1 May, in all the sowings of *C. capsularis* the water content gradually decreased with age, the highest water content being at the seedling stage. In *C. olitorius* also the same sequence was followed, but in 1 May sowing a higher water content was noted from the 90th to the 120th day, and for 30 June sowing from the 60th to the 90th day. Among all the sowings, in both the species, the highest water content reached was in 31 May sowing, and 30 June sowing was second in this respect.

TABLE IV

Height in cm.

Species	Date of sowing	Days after sowing						
		30	60	90	120	150	180	Rate of increase per day
C. capsularis	April 1	40·50	136·25	215·33	314·17	352·00	363·08	2·01
	May 1	53·33	199·08	298·83	331·25	..	..	2·76
	May 31	50·83	156·50	214·00	257·75	..	..	2·14
	June 30	28·67	110·67	156·17	193·00	..	..	1·60
C. olitorius	May 1	46·58	206·42	310·33	360·67	..	..	3·00
	May 31	43·92	143·58	214·42	269·66	..	..	2·24
	June 30	22·75	99·92	188·50	188·70	..	..	1·57

As the sowing was delayed from 1 April to 30 June in *C. capsularis* and from 1 May to 30 June in *C. olitorius* the maximum height reached at the time of fruiting gradually decreased. The heights reached at the time of fruiting were 356, 332, 240, 152 cm. and 360, 236, 152 cm. for the four sowings of *C. capsularis* and three sowings of *C. olitorius* respectively. The rate of increase in height was highest in 1 May sowing of *C. capsularis*, but the ultimate height reached was greatest in 1 April sown plants with longer vegetative period. In *C. olitorius*, in all the sowings and in all the stages of growth, height gradually decreased with the lateness of sowing.

The rate of growth in height was very irregular and follows the same sequence as the dry weight. The period of greatest increase was between 30-60th day in all the sowings, except in the first sowing of *C. capsularis* and in the last sowing of *C. olitorius*. In the former case, the highest rate was between 90th to 120th day, and in the latter, between 60th to 90th day.

The average rate of increase in height per day gradually decreases in both the sowings from 1 May to 30 June. In *C. capsularis* the rate in 1 April sowing was less than that of 31 May sowing.

TABLE V

Number of nodes

Species	Date of sowing	Days after sowing						Increase in No. of nodes per day
		30	60	90	120	150	180	
C. capsularis	April 1	15·00	34·90	60·16	81·33	104·33	105·00	0·58
	May 1	14·49	43·50	72·16	88·30	..	..	0·73
	May 31	14·33	37·17	52·33	70·33	..	..	0·58
	June 30	11·17	30·33	46·83	55·00	..	..	0·45
C. olitorius	May 1	14·66	47·00	77·66	107·66	..	..	0·89
	May 31	12·83	36·00	61·67	72·66	..	..	0·59
	June 30	11·50	27·33	45·83	51·33	..	..	0·42

Number of nodes in both the species at all the stages, when sown between 1 May to 30 June, gradually decreased with lateness of sowing. In 1 April sowing of *C. capsularis* the ultimate number of nodes was largest due to prolonged vegetative period.

From the point of view of fibre production a lesser number of nodes is of advantage for jute. The ratio of height to the number of nodes, that is the average length of internode, recorded at the final stage, in the successive sowings of *C. capsularis* has been calculated to be 3·57, 3·75, 3·66 and 3·50 and for *C. olitorius* 3·45, 3·74 and 3·69 respectively. Thus *C. capsularis* had the longest internodes in 1 May sown plants and in *C. olitorius* in those of 31 May sowing.

Circumference at the base of stem

The mean values of the circumference at the base of the stem for the four sowings of *C. capsularis* and the three sowings of *C. olitorius* are 7·77, 9·43, 6·37, 3·48 and 8·09, 5·57 and 3·33 cm. respectively. Thus with the lateness of sowing, except in the case of *C. capsularis* sown on 1 April the circumference of the stem gradually diminished. The circumference of the stem in the last sowing was almost half of the previous one and one-third of the 1 May one. In *C. olitorius* the proportions, though a little less, almost correspond to those of the other species.

Meteorological Factors

Monthly mean values of the meteorological data of maximum temperature, minimum temperature, rainfall, relative humidity, total hours of bright sunshine and length of days are given in fig. 1.

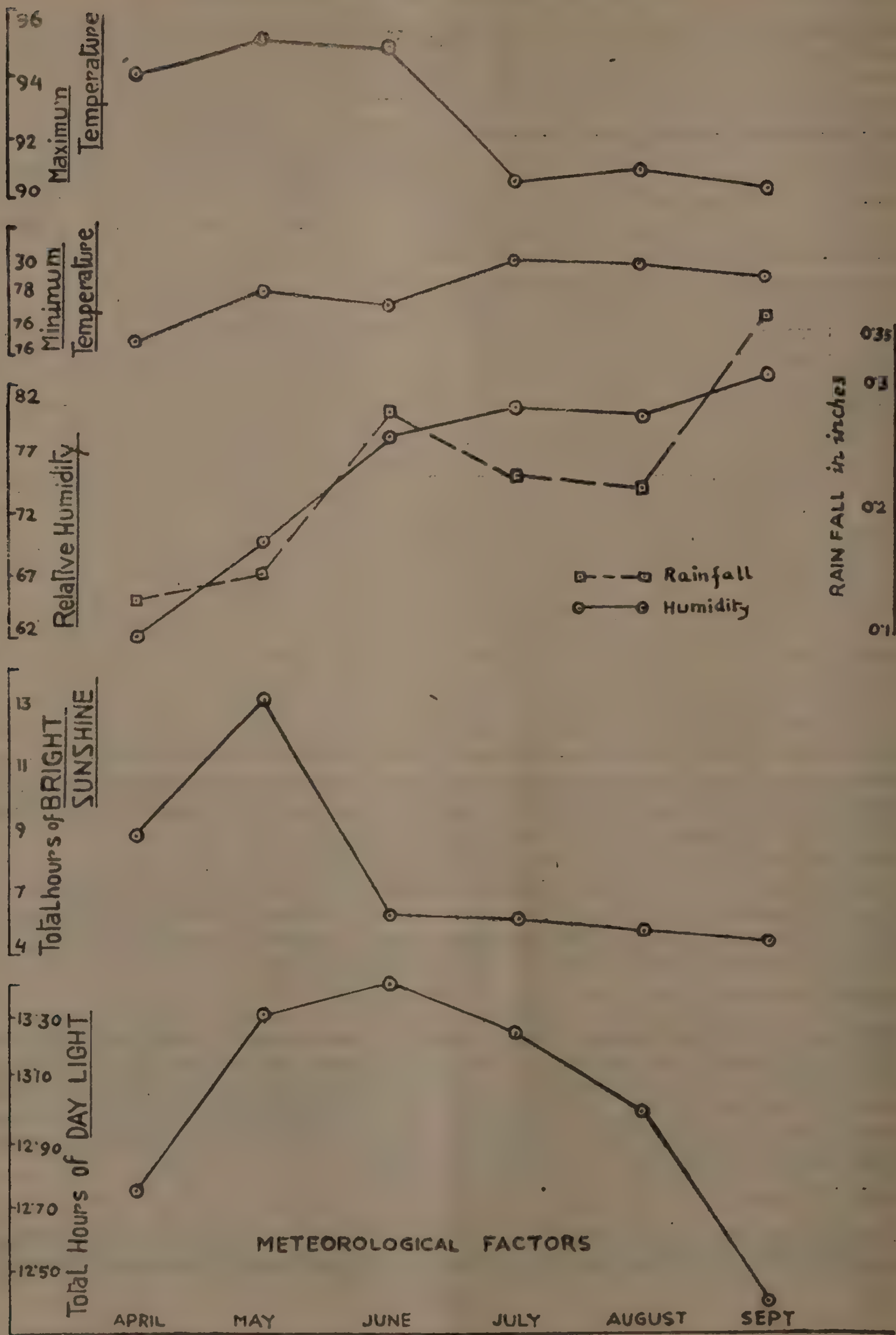

Fig. 1. Meteorological factors during the growing season of Jute

The plants of the successive sowings were exposed to different conditions of climatic factors at different stages of development. In *April*, the maximum temperature was high, minimum low, rainfall and humidity low, bright sunshine period and the daily light period long. In *May*, both the maximum and minimum temperatures were high, rainfall and humidity slightly higher, longhes period of bright sunshine, closely approaching the total hours of day light period. In *June*, the maximum and the minimum temperatures were high, humidity still higher, rainfall much higher, total hours of bright sunshine much lower, and the day length was the longest. In *July*, the maximum temperature was low, the minimum temperature highest, rainfall medium, humidity high, total hours of bright sunshine low and the day length gradually decreasing. In *August*, the maximum temperature was low, the mimimum temperature high, rainfall medium, humidity lower, total hours of bright sunshine low and daily light period still lower. In *September*, the maximum temperature was low, the minimum temperature high, rainfall and humidity highest, total hours of bright sunshine and the total period of day light lowest.

Discussion

The results of this experiment indicate in conformity with the investigations of Sen Gupta and Sen [Part I] that with the lateness of sowing the vegetative period of both the species of Jute is gradually shortened, and the plants flower almost at the same period irrespective of the sowing time. The difference of 90 days in sowing delays bud initiation only by 30 days in *C. capsularis* and in *C. olitorius* a delay of 12 days in bud initiation has been recorded for a difference of 60 days in sowing. The probable causes have also been discussed by them and the influence of gradually shortening photoperiod at the time of flowering seems to be the most important, jute being a short day plant [Sen Gupta and Sen 1946].

It should be remembered, that the plants of different sowings are exposed to similiar set of climatic factors at different ages and stages of development and several factors vary simultaneously during the period. A clear correlation, therefore, of the developmental changes to the environmental factors is hardly possible. A few general observations on the influence of the different factors may however be attempted.

The daily rate of accumulation of dry matter is optimum under the conditions of 1 May sowing. Both the species of jute of this sowing maintain the highest level of dry weight in all the stages as compared to other treatments. In *C. capsularis*, this set though sown 30 days after the previous one, the dry weight after 1 July i.e. after three months from the sowing time and four months from the sowing time of the previous one is almost the same. The initial gain of 30 days could not be maintained in the early sowings, though exposed to the same conditions later on. The first April sown plants were exposed to lower minimum temperature and humidity in the first month and these may have some effect. If we consider the changing meteorological factors during the whole period of the experiment it seems that low maximum temperature, total hours of bright sunshine and high relative humidity and rainfall from July to September are the main causes for the slower rate of growth in the late sowings. Of the different factors, apart from high temperature, the most dominant one seems to be the exposure to the total hours of bright sunshine in the early stages of the growth and development of the plants. Effect of longer period of bright sunshine in April and May becomes favourable for dry weight increase due to increased photosynthesis. Plants sown in May receive the maximum period of bright sunshine. The results obtained, open up an important point for investigation as to whether the total hours of bright sunshine in the early phase have any effect in the later stages of growth.

The low rate of growth in the last sowing of both the species can directly be correlated with low temperature, high minimum temperature and low total hours of bright sunshine, the high rainfall and relative humidity and the decreasing day length may also have some effect. Gregory [1926] observed in barley that assimilation rate is directly correlated with day temperature and radiation, and negatively with night temperature. The thirtyfirst May sown plants are exposed to these factors that are intermediate between 1 May and 30 June, and this intermediate climatic conditions explain its growth rate which is also in between the two. Growth in height was also highest for 1 May

sowing and considering all these effects of environmental factors it can be concluded that this is the optimum sowing time for both the species of Jute under the conditions of study, in conformity with the observations of Sen Gupta and Sen [1947].

SUMMARY

1. Two species of Jute *Corchorus capsularis* L. (D 154) and *C. olitorius* L. (Chinsura green) were sown in replicated plots at an interval of one month, there being four sowings of *C. capsularis* from 1 April to 30 June and three for *C. olitorius* from 1 May to 30 June.

2. In both the species the vegetative period was progressively reduced as the sowing was delayed, *C. capsularis* flowering from the middle of August to the middle of September and *C. olitorius* from the end of August to early September.

3. As the sowing was delayed from 1 May, the dry weight, height, and the number of nodes at the fruiting stage progressively decreased. The first April sown plants had a lower growth rate than the second sowing, but with prolonged vegetative period had ultimately the highest dry weight, height, and the number of nodes. The highest growth rate for every sowing was between the ages of 30 and 60 days in each species.

4. Influence of meteorological conditions on the growth and development of both the species has been discussed and 1 May sown plants have been found to be exposed to the optimum conditions from the point of view of the rate of growth.

5. High temperature, long daily total period of bright sunshine in the early stages, high humidity and rainfall, at the later stages are factors favourable for growth.

ACKNOWLEDGEMENTS

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ROOTSTOCKS FOR ACID LIME

[*Citrus aurantifolia* (Christm) Swingle]

By K. C. Naik, B.Ag. (Bom.), M.Sc. (Bristol), Fruit Specialist, (Madras)

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(With one text figure)

THE optimum nursery technique in raising budded lime plants was discussed in a previous publication by the author [1939]. It was followed by an account of the observations and findings on the pre-orchard life of certain varieties of citrus when employed as rootstocks for lime [1940]. The latter publication also contained the details of plant material and the layout employed in establishing a lime rootstock trial at Kodur in 1938. From the date of setting out the experimental trees in October 1938, regular observations combined with quantitative records of individual tree performance have been collected such that it is now deemed possible to assess the rootstock influences during roughly the first eight years of orchard life of the trees. In effect, therefore, the present contribution aims to be the progress report of the lime rootstock trial at Kodur during about the first eight years after its inception.

To facilitate ready reference the following information on the material utilized in the trial as also on the plan of lay-out is furnished :

TABLE I

Key to treatments, details of plant material used, layout etc., (Rootstock trial with acid lime, Kodur)

1. Plot size	60′ × 20′ (0·0275 acre)
2. Number of replications	6
3. Number of trees in each plot	3
4. Spacing	20′ on the square
5. Scion material	Acid lime, seedling tree No. 4/6
6. Date of planting	20th and 21st October 1938

Key to treatments	Rootstock variety	Date of sowing	Extent of roguing out		Date of budding
			In seed bed (per cent)	In nursery bed (per cent)	
1	2	3	4	5	6
A . .	*Jamberi* (rough lemon) (*C. limon*)	19-12-35	..	40·00	15-7-1937
B . .	*Gajanimma* (*C. pennivesiculata*)	18-11-35	52·50	40·00	18-7-1937
C . .	Acid lime	23-11-35	14·00	40·00	14-7-1937
D . .	Acid lime un-worked scion seedling	23-11-35	14·50	40·00	..

At the time of planting of the finally selected batches of trees in the orchard sites, growth measurements in terms of rootstock and scion stem diameter and plant height were collected and these as well as the growth increments made by the rootstock stems from the date of budding to that of final planting were analyzed statistically. On the basis of these data it has already been reported that, *jamberi* (rough lemon) had produced the largest rootstock stem thickness at the time o planting, while acid lime rootstock had produced the least. In regard to increments of stem thickness made up to the time of planting, acid lime rootstock was found to be significantly inferior to the other two rootstocks, while in respect of plant height *jamberi* and unworked lime seedlings were significantly superior to the other two treatments at the time of planting. These initial growth differences are summarized here so as to facilitate the evaluation of tree performances during the orchard life of the trees in the subsequent years.

Orchard performances

From the producer's point of view no less than that of the investigators, the most obvious and important influence of a rootstock on the scion is reflected in tree growth or vigour, tree health, and fruitfulness. The available data on these as well as on other apparently secondary items are analyzed and presented in the following pages.

I. *Tree growth or vigour*

Scion stem circumference.—In Table II are set forth the analyzed data relating to scion stem circumference of the trees as collected on 14-3-1946, *i.e.*, roughly 89 months after planting.

TABLE II

Summary of results relating to the circumference measurement of scion stems of budded trees and of stems of unworked scion seedling trees as on 14-3-1946 (Acid lime rootstock trial)

Particulars.	A	B	C	D	General mean	S. E. D. M.	Level of significance	Critical difference
1	2	3	4	5	6	7	8	9
Mean stem circumference per treatment in cm.	62·00	57·73	56·44	48·28	56·15	2·04	P0·05 P0·01	4·34 6·01
Mean stem circumference as per cent of the general mean	110·42	102·81	100·52	85·98	100·00	3·63	P0·05 P0·01	7·73 10·70

Conclusion.—At 5 per cent level of significance $\overline{\text{A B C}}$ D (Treatments under or above the same bar do not differ significantly from each other).

Jamberi continues, therefore, to maintain its prominent position for producing thicker lime scion stems, differing significantly from the acid lime rootstock as well as the unworked scion seedlings, with *gajanimma* appearing close behind the *jamberi*. By the co-variance method of analysis, however, the regression coefficient was not significant. At the end of about 89 months after planting the trees, the position, therefore, is that the budded trees are distinctly superior in respect of stem size to the seedlings ; and among the former, the trees on *jamberi* rootstock have produced significantly larger stem size than those on lime rootstock.

Tree spread—Measurements relating to the tree spread were collected on 16-2-1946—first north to south and then west to east. The mean of these two measurements for each tree was then taken as the mean for that tree. The results of analysis of the data are presented in Table III.

TABLE III

Summary of results relating to tree spread measurements as on 16-2-1946 (Acid lime rootstock trial)

Particulars	A	B	C	D	General mean	S. E. D. M.	Level of significance	Critical difference
1	2	3	4	5	6	7	8	9
Mean spread per treatment in cm.	569·37	570·90	558·27	511·99	552·63	12·81	P 0·05 P 0·01	27·30 37·75
Mean spread as per cent of the general mean	103·03	103·31	101·02	92·65	100·00	2·32	P 0·05 P 0·01	4·94 6·83

Conclusion—At 5 per cent level of significant $\overline{\text{B A C}}$ D (Treatments under the same bar do not differ significantly from each other).

It is obvious from the foregoing data that unworked seedlings have an erect habit and cover much less ground than the budded trees after about 88 months of orchard life. Among the budded trees on the three rootstocks the differences are not significant, and they may therefore, be grouped together. As in the case of scion stem, the co-variance method of analysis showed that the regression was not significant.

The above data have incidentally brought out the futility of the wide-spread prevalent practice of raising lime plantations with a close spacing of even 12 feet or less in some parts of Madras. The erect growing seedlings have a spread of about 17 feet in less than eight years of planting ; and they are still growing. It seems safe, therefore, to state that less than 20 feet spacing is to be deprecated for this fruit under loamy soil conditions as those at Kodur, while the optimum spacing may be about or more than 25 feet.

Tree height. Height measurements of all the trees under the trial were also recorded on 16-2-1946. On analysing these data, however, it was found that the treatments did not differ significantly from each other. The mean height of the trees on *jamberi*, which was the highest on the date of measurement, was 389·30 cm., while the shortest trees were the seedlings with a mean value of 364·69 cm. The difference between the two apparent extremes was less than the critical difference, which was 36·89. By the method of analysis of co-variance also no significant differences were obtained.

Stock-scion congeniality. In April 1946 field observations were collected to determine the degree of congeniality between the scion and the three rootstocks included in the trial. The summarized observations are given in the following Table, and these serve to indicate in some measure the differential growth rates in the three scionic combinations.

TABLE IV

Summary of observations on the growth at the bud-union as in April 1946 (Acid lime rootstock trial)

Rootstock	Percentage of trees in which stock stems are over-grown	Percentage of trees in which scion stems are over-grown	Percentage of trees showing smooth bud-joints
Jamberi	11·11	27·78	61·11
Acid lime	22·22	5·56	72·22
Gajanimma	72·22	5·56	22·22

The fact that lime rootstock has so far produced smooth union on the largest number of trees, is a result that was normally to be expected. *Jamberi* is far behind in the second rank. The markedly over-grown stock stem in most trees budded on *gajanimma* marks out this stock as the least promising ; at any rate it is a treatment that deserves to be specially watched in future.

II. *Tree health*

Evidence has been produced by Fennah [1940] from his studies of limes grown in St. Lucia, Dominica and Montserrat to the effect that seedling lime trees are susceptible to die-back disease, while rough lemon and bitter orange stocks are susceptible to gummosis. Smith [1936] also reports from Jamaica that wither-tip disease is most frequent on lime trees when there is some incompatibility of stock and scion, while Cheema *et al* [1928] had also noted in Western India that different citrus varieties manifest different degrees of susceptibility to die-back on rough lemon rootstock. In the trial under way at Kodur, the trees fortunately have not had any appreciable damage from gummosis. But die-back of shoots possibly due to wither-tip disease was not an uncommon feature in the experimental plantation. Every attempt was, however, made to cut back the dead shoots as frequently as possible, and the weights of such prunings were recorded. The analysis of these recorded weights of prunings has been made with the hope that the data might offer an indication of the root-stock influence in so far as the incidence of die-back is concerned.

Table V

Summary of weights of prunings—Acid lime rootstock trial

Treatment	Total weight of prunings from September 1940 to March 1946
A. *Jamberi* rootstock	1817·45 oz.
B. *Gajanimma* ,,	2098·45 ,,
C. Acid lime ,,	1629·82 ,,
D. Seedling trees	1628·69 ,,

There is clearly a difference among the treatments in favour of unworked seedlings and budded trees on acid lime stock. The largest quantity of prunings being from trees on *gajanimma* which were shown to be the least congenial scionic combination and the next highest from trees on *jamberi*, which is also the next in the degree of uncongeniality, the indications are strong in favour of Smith's [1936] inference to the effect that the congeniality is an important factor in determining the extent of damage by die-back or wither-tip diseases.

III. *Yield*

In Fig. 1, the yields are plotted against age in order to bring out clearly the course of yield increments from year to year, till the close of July 1946. These show the relatively poor cropping capacity of the seedlings in the first eight years of orchard life, as also the higher cropping propensities of the trees on *gajanimma* and lime rootstocks in the same period. The differences were the greatest between the unworked seedlings and trees on *gajanimma* in 1944. On 30-6-1944, the accumulated yields on *gajanimma* were 4,527 fruits, while on seedlings the number was only 472, which is roughly one-tenth. These large differences have narrowed down to less than 50 per cent by 31-7-1946. A more definite picture is available by the analysis of accumulated yields up to 31-7-1946, which are also sufficiently striking to compel notice, as is seen from Table VI.

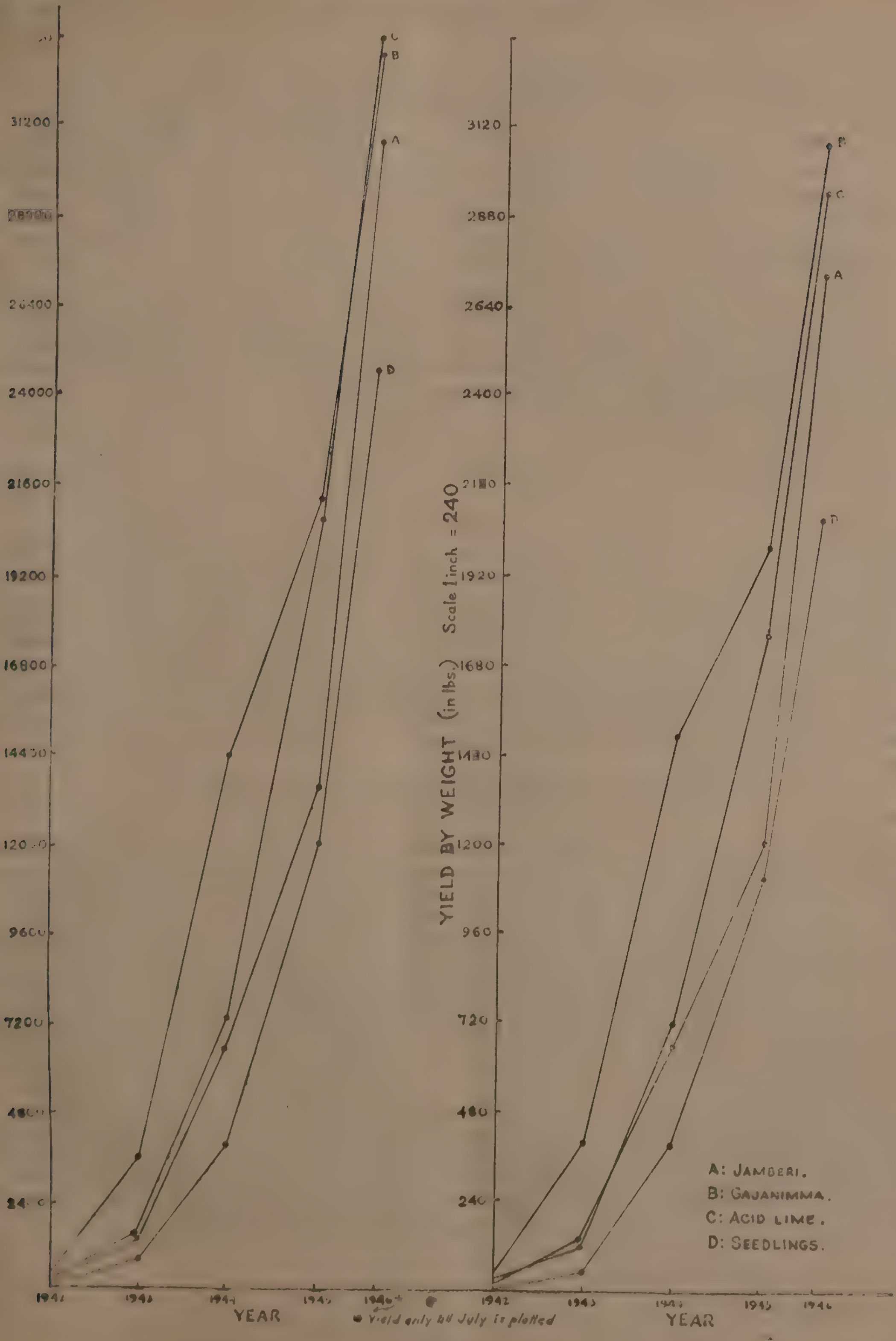

FIG. 1. Showing the fruit yields in acid lime rootstock trial.

TABLE VI

Summary of accumulated yields (by weight) till the end of July 1946

Particulars	A	B	C	D	General mean	S. E. D. M.	Level of significance	Critical difference
Mean accumulated yield per treatment in lb.	267	380	327	201	289	21·14	P-0·05 P-0·01	45·05 62·30
Mean accumulated yield as percentage of general mean	92·39	131·49	113·15	69·55	100·00	..	..	..

Conclusion at per cent level of significance B C A D (Each treatment differs significantly from the other).

The significantly heavier crop on budded trees than on seedlings and on *gajanimma* than on the other two root-stocks are clearly established from the above Table. Expressed on the acreage basis, the accumulated yields up to 31 July 1946 would be as under :

Particulars	Per acre	
	No.	Weight in lb.
On *gajanimma*	437,945	42,036
On *jamberi*	314,600	28,545
On acid lime	379,242	33,812
On acid lime Seedlings	249,976	21,988

It will be generally conceded that, regardless of the possible variations in ranking of treatments that may result with the ageing of the trees, the foregoing differences are so large as to induce the lime grower to go in for budded lime plantations in preference to seedlings and particularly for plantations on *gajanimma rootstock*.

In Table VII are presented data to show the progress of harvests made in the experimental area.

It has been noted that the unworked seedlings have reached the first bearing stage about five months later than the budded trees. By 1942, *i.e.*, the second year of bearing of the budded trees and the first year of the seedlings, the latter had produced a crop roughly on only one-half to one-third of the number of bearing budded trees. The bearing in all seedlings was complete only in 1944, while in budded trees that stage was reached a year earlier. The actual harvest in 1944 when all the seedlings and budded trees produced a crop for the first time were such that the seedling trees accounted for roughly one-fourth of the crop produced by budded trees on *gajanimma*. It is, therefore, established that material differences exist between the treatments not only in terms of yield but also in the earliness of bearing, according to the latter of which the treatments appear in the following descending order :

1. On *gajanimma*
2. On Acid lime
3. On *Jamberi*
4. Unworked seedlings

Table VII

Showing the progress of bearing up to 1946

(Acid lime rootstock trial—date of planting—October 1938)

Treatment	Number of trees.	Number of trees which bore fruit in						Number of fruits borne in					
		1941	1942	1943	1944	1945	1946	1941	1942	1943	1944	1945	1946
On *jamberi* (rough lemon)	18	2	11	18	18	18	18	4	37	1,217	6,428	13,534	30,693
On *gajanimma*	18	5	14	18	18	18	18	17	233	3,447	14,301	21,190	33,090
On acid lime .	18	3	10	18	18	18	18	13	62	1,273	7,008	20,652	33,580
Seedling .	18	..	5	17	18	18	18	..	47	606	3,841	12,142	24,610

IV. *Fruit quality*

The influence of citrus rootstocks on the chemical content of fruit such as acidity, which is the most important ingredient of the lime from the point of view of trade, is not recognized by all workers. While Powell [1930] denies any stock influence on acidity of the scion fruits, and Webber [1926] is of the same view, Hodgson *et al* [1938] and Richards [1940] have adduced arguments to prove that citric acid and soluble solids contents vary appreciably between different scionic combinations, the former adding that rough lemon produces the lowest acid content and high soluble solids-acid ratio in Bearss lime. In Table VIII are presented the data collected at Kodur from some physico-chemical tests made with samples containing 18 fruits in each of the four treatments.

Table VIII

Summary of results of physico-chemical tests made on 18-5-1946
(Acid lime rootstock trial)

Treatment	Acidity (citric acid per cent)	Brix
A. *Jamberi* rootstock	7·59	8·60
B. *Gajanimma* „	7·73	8·40
C. Acid lime „	7·62	8·20
D. Seedling trees	7·21	8·50

Similar analysis had been made once a year from 1943, but although the data are conflicting presumably because of the variations in season and partly due to defective or unstandardized sampling prior to 1945, their general trend is such as to indicate that the differences between the treatments in regard to acid or total soluble solids contents are not appreciable. At any rate, more work in the line for a few more seasons would be necessary before any definite inferences would be warranted.

In Table IX are shown the figures relating to individual fruit weights in each of the five years.

TABLE IX

Showing the individual fruit weights under rootstock treatments

Treatment	Individual fruit weights in the year in oz.				
	1942	1943	1944	1945	1946
A. On *jamberi*	2·31	1·49	1·64	1·43	1·42
B. On *gajanimma*	1·50	1·78	1·68	1·50	1·47
C. On Acid lime	1·61	1·74	1·64	1·37	1·40
D. Seedling trees	1·68	1·29	1·62	1·47	1·35

As in the case of physcio-chemical analysis, the above data seem conflicting and not consistent from year to year. Even after disregarding the 1942 and 1943 yields as of pre-full bearing stage, it is difficult to account for some of the variations such as that between budded limes on lime and seedlings in 1945 and 1946. At any rate the differences are too little to be safely attributed to seasonal variations or treatments.

DISCUSSION

The data so far available on the orchard performance of certain rootstocks for the acid lime do not by any means justify a categorical answer to any of the possible questions from the lime producers on the relative merits of seedling *versus* budded lime plantations or on the influences of various rootstocks for lime. While, the budded lime has certainly shown superior orchard performance during the first few years of orchard life, one should be prepared for some surprises in store in future. As an illustration of the varied indications afforded by the trial, it will be noted that during 1944, the trees on *gajanimma* yielded crops roughly four times that on seedlings, while in 1946 the margin was so narrowed down as to be not very spectacular. While this fact establishes the already well-known fact that seedlings come late to the bearing stage, it has at the same time revealed the slow rate at which the defects of the rootstock come to light. Thus, *gajanimma* has gradually begun to show a tendency towards the production of uneven bud-unions, which feature does not augur well for this scionic combination. There is no knowing if such rootstock influences will not accentuate as the trees age. At the same time with its smooth bud-union and steady pickup in yielding capacities, lime on lime rootstock is emerging as a promising combination. This is in accordance with the observations made in Egypt, that lime makes a suitable stock for scions of its own kind [Brown, 1924]. These various features necessitate caution in drawing inferences. Nevertheless, it seems safe to suggest that, because of material differences in early bearing, superior tree growth during early years, relatively small amount of dead wood on the trees, and generally heavier yields, budded trees of lime should be preferred in future plantations. More definite recommendations in the matter of rootstock preferences, it would be clearly premature to make at this stage of the trial.

From a review of the Bearss lime rootstock trial eight years after planting in California, Hodgson [1936] has concluded that on all stocks the lime scion overgrows the stock at the bud-union, including on rough lemon. In the present studies, such a feature has not been found to hold good with the acid lime at Kodur. An explanation to this varying behaviour is perhaps to be found in the inferences of Fennah [1940], according to whom the growth at the bud-unions of lime on certain stocks such as sour orange is greatly influenced by local environment *i.e.*, the stock may develop equally with the scion or be overgrown by it according to locality. It has to be added, however, that Bearss lime is of the Tahiti or Persian group, while the lime in the present trials is the common lime. The former is also reported to be more vigourous in growth.

The last year's terrific cyclonic visitation in the northern parts of Madras Province has brought to the fore the necessity for planting in the orchards lime trees with the maximum anchorage power. Fennah [1940] has shown that in the West Indian seedling lime under such adverse conditions as water logging, portions of the root system fail, due to the death of the outermost fine rootlets. This dying of tissues is not uncommon in South India although in certain sections the roots may periodically regenerate themselves. Such periodic death of rootlets combined with the fact that the seedling lime is known to be comparatively shallow rooted, may make it prone to special damage by high winds. Actually many seedling lime trees fared badly in the last year's cyclone in the Circars, though fortunately Kodur was outside the affected zone. With a rootstock possessing a deep and extensive root system, it is to be expected that the budded lime would withstand storms and high winds better. Although no data have been adduced in support of this presumption in the present paper, previous studies at Kodur have shown that *gajanimma* has an enormous foraging power, it having a root spread of 543·30 cm. on a 21 months old sweet orange plant budded on it. It has also a stout tap-root, is deep-rooted and has fairly abundant and well distributed fibre throughout the root system. As compared to it the acid lime has sparse fibre except towards the extremities and on its tap-root, while *jamberi* possessess a stout and deeply anchored tap-root, and an abundance of coarse and spreading laterals [Naik, 1940]. The important functional aspect of the root *viz.*, that of anchoring the plant in the soil can obviously be better performed when the root system is deep and extensive ; and in this respect the combination of a deep and extensively rooted stock with lime scion should offer obvious advantages. Budded lime plantations on *gajanimma* or *jamberi* may therefore afford special advantages in the Circars, where the seedling limes are now subject to occasional devastation from high winds or cyclones.

The foregoing study does not mean that a shallow rooted lime has no value as a rootstock. In certain delta areas with high water tables and in ill-drained soils, lime has long been known to thrive better than any other citrus, and is further found to be the least susceptible to stem and root diseases which are either caused or accentuated by the wet soil for long periods. Experience has also shown in Egypt that in light or sandy soils, lime is a better rootstock for lime than bitter orange [El Sawy, 1936]. On the other hand, Fennah [1940] has shown that seedling lime trees are susceptible to drought conditions, which feature causes a die-back of rootlets and also of the whole or sections of the tree. These indicate that budded plantations may have special value under a diversity of conditions, provided the right rootstock is chosen to suit the particular soil conditions and environment.

Summary

1. The paper sets forth the growth and yield performances of acid lime trees grown as unworked seedlings and as budded trees on *jamberi* (rough lemon), *gajanimma* and acid lime rootstocks, during a period of about eight years after planting at the Fruit Research Station, Kodur.

2. Although it has been shown that there is a need for prolonged observations before the final appraisal of the stocks for lime is made or the relative merits of budded lime and seedling plantations are determined, some of the differences between the treatments during their early orchard life are pointed out as sufficiently marked to bring out the superiority of budded plantations.

3. The main features associated with each treatment during the first seven to eight years of orchard life are as follows.

(*a*) Growth : the budded trees have clearly recorded larger spread and scion stem circumference than the seedlings.

(*b*) Early bearing : The budded trees have also been shown to be more precocious than the seedlings.

(*c*) Yield : *Gajanimma*, lime and *jamberi* appear in the order given here in respect of heavy-yielding capacities, with seedlings in the bottom rank.

(*d*) Quality : Data are conflicting in this respect and further work seems necessary.

(e) Health : Lime seedlings and trees on lime root-stock are the least affected by die-back or withertip, with trees on *gajanimma* showing the largest amount of dead shoots.

(f) Compatibility : Smooth bud-unions are associated with lime on lime, while on *gajanimma* there are indications of incompatibility.

4. The possibility of mitigating the influence of adverse soil or environmental conditions by the selection of the right stock for lime is indicated.

5. Less than 20 feet spacing for lime is to be deprecated in lime seedling or budded plantations.

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VEGETATIVE PROPAGATIONAL METHODS AND THEIR RELATION TO TREE PERFORMANCE IN THE MANGO, *MANGIFERA INDICA* L.

By K. C. Naik B.Ag., (Bom.) M.Sc. (Bristol), Fruit Specialist, Kodur (Madras)

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(With three text figures)

WITH a view to determine one or more methods of vegetative propagation which can advantageously replace the commonly adopted method of inarching in mango, work has been in progress for over eight years now at the Fruit Research Station, Kodur. A preliminary report on the results obtained in the seed and nursery beds has already been published by the author [1941]. Some of the field or orchard studies which were initiated with the above-mentioned end in view, were also referred to briefly in this earlier contribution. Since the trees under these field trials have now made over five years of growth in the orchard, a stage has been reached when the important observations and findings recorded thus far are deemed to be of sufficient value and interest to merit publication.

I. *Inarching, root-grafting and double-grafting*

This trial with Neelum and Bangalora scion varieties propagated by inarching, root-grafting and double-working was initiated in 1939 as per the details of the treatments and layout furnished below.

TABLE I

Key to treatments, details of material, layout, etc., (Mango propagational trial)

1. Plot size	40′ × 120′ (0.11 acre)
2. No. of trees per plot	3
3. Spacing	40′ on the square
4. No. of replications	6
5. Scion trees	One Neelum and another of Bangalora
6. Date of sowing seeds	26th and 27th June 1938

Key to treatment	Treatment	Date of vegetative propagation	Date of planting
A	Neelum inarched	5-7-1939	1-12-1939
B	Bangalora inarched	4-7-1939	1-12-1939
C	Neelum root-graft	11-7-1939	1-12-1939
D	Bangalora root-graft	11-7-1939	2-12-1939
E	Neelum, Bangalora, Seedling (double worked)	17-2-1939 7-7-1939	2-12-1939
F	Bangalora, Neelum, Seedling (double worked)	18-2-1939 6-7-1939	2-12-1939

Scion stem circumference, height and spread measurements of every tree were collected at the time of planting as well as annually thereafter. In Table II are given the growth data as collected on 5 January 1946 (for spread and height) and 21 January 1946 (for stem circumference) *i.e.*, roughly six years after the trees were planted, and analyzed by the simple analysis of variance.

TABLE II

Summary of growth measurements as collected in January 1946 (Mango propagational trial)

Treatment	Stem circumference		Mean height		Mean spread		Remarks
	In cm.	As per-cent of general mean	In cm.	As per-cent of general mean	In cm.	As per-cent of general mean	
A	54·32	99·07	324·09	93·03	498·63	100·37	Stem circumference was collected at 1" above the centre of graft-joint in all except in double-worked trees, where it was collected at 1" above the upper graft-joint. Spread is the mean worked out by taking the measurements north to south and west to east of the trunk.
B	61·72	112·57	396·59	113·83	514·74	103·62	
C	54·59	99·56	330·40	94·84	494·65	99·57	
D	61·04	111·32	366·38	105·17	513·66	103·40	
E	49·65	90·55	333·88	95·89	494·60	99·54	
F	47·67	86·94	338·97	97·28	447·77	90·13	
General mean	54·83	100·00	348·38	100·00	496·78	100·00	
S. E. D. M.	2·81	5·12	18·23	5·23	19·79	3·98	
Level of significance P=0·05.	2·06	..	..	2·06	..	2·06	
Critical difference	5·79	..	37·55	..	40·77	..	

Conclusion.

1. Stem circumference — B D C A E F

2. Height — B D F E C A

3. Spread — B D A C E F

(Treatments under or above the same bar do not differ significantly from each other)

The consistently superior growth shown by Bangalora root-grafts and inarched plants, though not significantly larger by all the three standards of measurements, justifies the inference that Bangalora is a quicker or more vigorous-growing variety than the Neelum during early orchard life, among the inarched plants and root-grafts. The double-worked plants have exhibited poorest stem growth and tree spread in both the varieties. The data do not warrant any deductions regarding the growth difference between the root-grafts and inarched plants.

Records on yield till 1st July 1946 are plotted in Fig. 1, and these show that, yield records on the basis of number of fruits are not a correct index of mango productivity under any one treatment. Considering the yield by weight of fruits, it is noted that Bangalora as a variety and regardless of the propagational method is inherently more prolific than the Neelum. Between the propagational treatments, the inarched trees of Bangalora excel the other two treatments of the same variety,

with double-worked trees occupying the lowest rank, while in Neelum the position is reversed with double-worked trees on the top and the inarched trees yielding the least crop weight. The treatments have maintained consistently the above stated ranks, except with Bangalora inarched trees, which recorded poor yields in 1945 and with Neelum inarched trees, which produced high yields relatively in 1944. Almost the same features as referred to above are disclosed from the analysis of yields for the year 1946, presented in Table III, except that the observed differences were only significant between Bangalora inarched and double-worked trees of the same variety. When the yields were analyzed on the basis of number of fruits, however, the difference between the inarched and double-worked trees of Bangalora were found to be not significant.

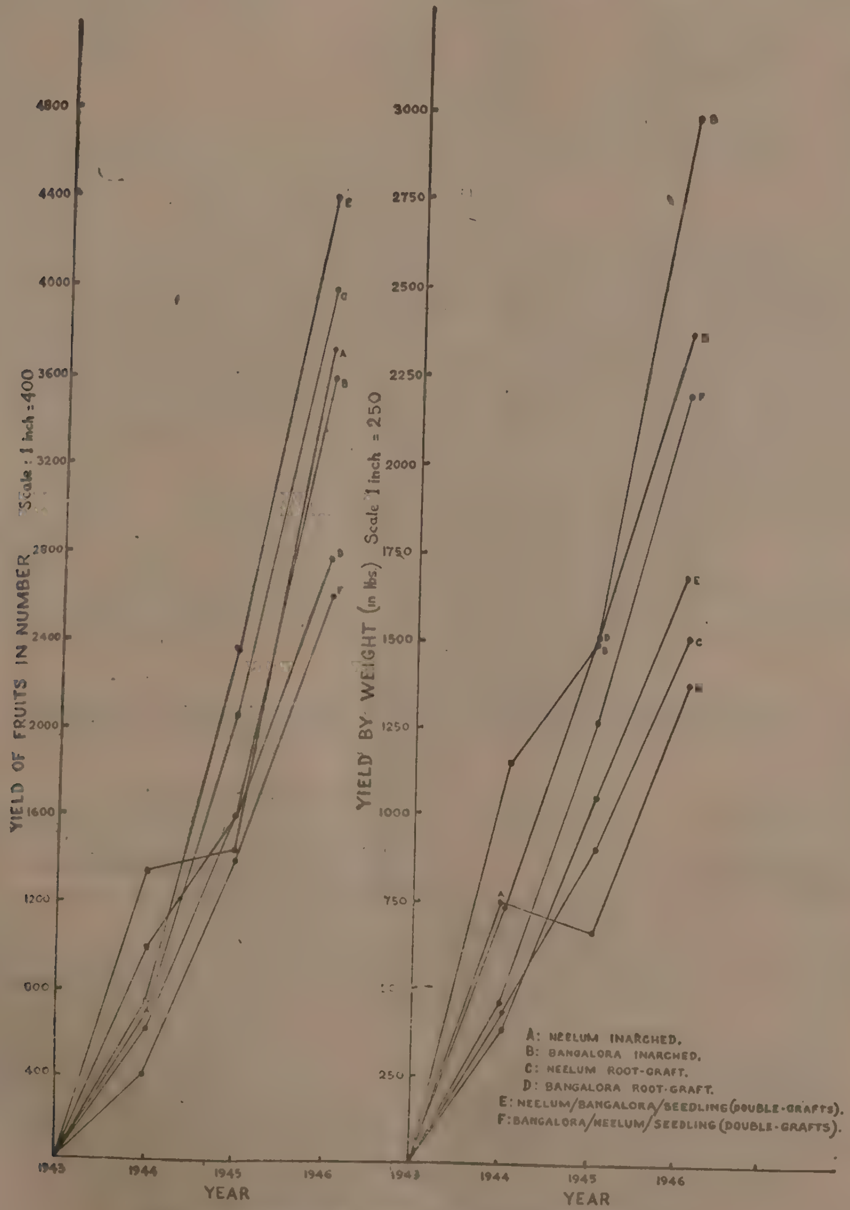

Fig. 1.—Showing fruit yields in mango propagational trial.

TABLE III

(Fruit yields in weight)

	A	B	C	D	E	F	General mean
Mean yield (in lb.)	76·81	165·99	84·42	131·42	93·78	122·16	112·43
Mean yield as percentage on general mean	68·32	147·64	75·09	116·89	83·41	108·65	100·00
Significance by 'Z' test (p=0·05)	Significant						
Critical difference	34·30						

Conclusion B D F E C A

(The treatments under or above the same bar do not differ significantly from each other)

Outside the experimental area but close to it, side-grafts and budded plants of Neelum and side-grafts of Bangalora from the same scion trees had also been planted at the time when the experimental trees were set out. Data on growth of these two batches are not available, nor do they lend themselves for a valid comparison. However, these three treatments have recorded a mean tree yield of 270 and 203 fruits respectively with Neelum and 103 fruits on side-grafts of Bangalora up to 30 June 1946. By weight, the yields were 89·44, 73·08, and 75·19 lb. respectively. These figures do not justify any inferences, nor do they provide any clue to the influence of these methods of propagation on tree yield.

II. *Double-working trial with four shy-bearing ultimate scion varieties*

In order to determine the influence of double-working on precocity, tree size and performance and also to see if a variety like Neelum, well-known for its productive and regular bearing tendencies, will transmit these desirable characters when used as an intermediate stem piece to a normally shy or irregular-bearing but choice fruiting ultimate scion variety, a trial was initiated on a small scale in 1940. In Table IV are given the key to treatments and the relevant details of the trial.

TABLE IV

Key to treatments, details of material, layout etc., (Mango double-working trial)

1. Plot size	20′ × 20′ (0·0092 acre)
2. No. of trees per lot	1 only
3. Spacing	40′ 28·28 feet × 28·28 feet Quincunx
4. Number of replications	8
5. Scion trees	Individual tree of each of the three scion varieties
6. Date of sowing seeds	July 1938
7. Date of first and second inarching	July 1939 and January 1940 respectively
8. Date of planting	30-5-1940

Key to treatments	Treatments		
	Ultimate scion	Intermediate stem	Rootstock
A	Himayuddin	Neelum	Seedling
B	Jehangir	Neelum	Seedling
C	Alampur Baneshan	Neelum	Seedling

As in the case of the trial discussed in the fore-going pages, growth measurements were collected under the trial at the time of planting and once a year thereafter. Statistical analyses of the data relating to stem circumference measurements as collected on 21-1-46 did not reveal any significant differences although the treatments appeared in the following descending order.

A . . . .
C . . . .
B . . . .

In regard to tree height, the analysis of measurements at the same period showed no significant differences between A and C, but trees of B (Jehangir) were relatively and significantly stunted with a mean tree value of 256·69 cm. as compared to 328·13 and 325·63 respectively for A and C, the critical difference being 54·35 at 5 per cent level of significance. In respect of tree spread, the mean values on 21-1-46 were 435·57 cm.; 399·38 cm., and 331·28 cm., respectively for A, C and B, with a critical difference of 72·42 at the same level of significance. Thus B was significantly less spreading than A but not than C. At the end of about six years of orchard life, therefore, Jehangir double-worked trees were relatively smaller in size than Himayuddin trees propagated in the same manner.

Although comparable batches of single-worked trees are not available, observations in a neighbouring orchard of the station planted to single-worked trees of the same three varieties indicate that double-working results in the production of relatively stunted trees at least till the sixth year after planting, a feature associated with Neelum and Bangalora double-grafts also. Between the single-worked trees of the different varieties, there is no perceptible difference in tree size.

Records on the blossom and fruit crop have been maintained in all the trees under experiment. At an early stage of these trials, certain blossom-biological studies undertaken at the same station had shown that the shy-bearing habit of the varieties such as Jehangir was primarily due to the very low proportion of perfect flowers found in the panicle [Naik, 1943]. This also explains the fact that although the double-worked trees in recent years had borne heavy crops of blossom, the actual fruit set was far below expectations, and in some seasons amounted to almost a complete failure. Further, in 1945 and 1946, a severe incidence of mango hoppers in this trial plot tended also to vitiate the results. On these grounds, the plotted yields in Fig. 2 cannot be taken to represent the correct position, except to establish that Jehangir possesses an inherently lower cropping capacity than the other two.

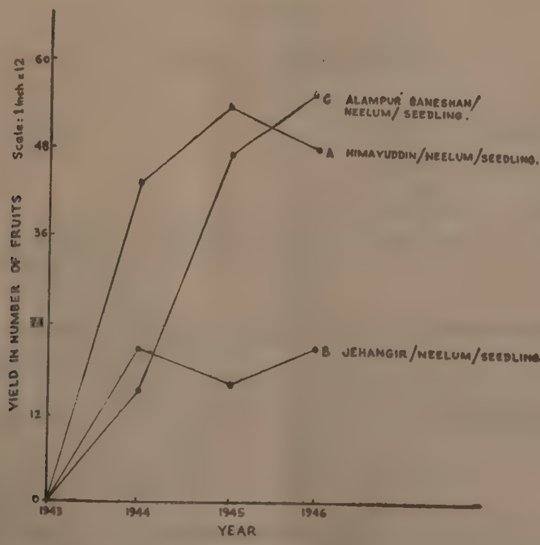

Fig. 2.—Showing the fruit yields in mango double working trial

On the basis of observations made on blossom crop it would however seem that double-worked plants of these three varieties flower earlier and better than single-worked trees in the neighbouring plots. The first crop for instance in these double-worked trees was obtained in the fourth year after planting on Jehangir and Himayuddin and on the third year on Alampur Baneshan, while from single-worked trees in the neighbouring plots they were obtained only six years after planting. The observed differences in the quantity of flower crop was even more striking, though in this respect an accurate idea cannot be presented in terms of definite figures.

III. *Inarching on seedling stocks of different age groups*

There is a wide-spread belief in the south of India, that mango trees on older rootstocks perform better under orchard conditions than on younger stocks. The common practice in this part of the country is to sow seeds in about June and inarch the seedlings after a year, commencing from the break of the south-west monsoon. Previous work [Naik, 1941] had shown that Neelum gave a cent per cent 'take' in July and August, while in May and November the 'take' was only 69 per cent and 94 per cent respectively. It was therefore felt that, if there was no influence of the age of seedling rootstocks on scion performance it would be advisable to perform inarching only in an optimum season like July-August. Three age groups were therefore chosen to determine if the seedlings within these three extensively used groups exert any influence on scion performance, and partly to determine the age group that would give the best scion performance and at the same time lead to high 'take' by inarching in the optimum season already determined. The selection of age groups was done therefore to enable the inarching to be done in a very bad season like May, in the best season like August, and in a fairly good season like November, which gave the three age groups of 10½ months, 13½ months and 16½ months respectively.

The trees were all raised as previously described by the author [1941] from one scion parent as in other trials and also on seedling rootstocks of one monoembryonic tree. The trees were planted on 31st December 1939 at the rate of 12 per treatment and three per plot, *i.e.* adopting four replications. In the first year of their orchard life as well as in every year there after till 23 January 1946, no significant differences were obtained between the treatments in respect of any standard of growth measurements. Neither was there any appreciable difference between the treatments in regard to yield as is seen from Fig. 3 and also as borne out from statistical analysis given in Table V.

TABLE V

Fruit yields by weight

Treatments :

A Neelum grafts on 10½ months old rootstocks

B Neelum grafts on 13½ months old rootstocks

C Neelum grafts on 16½ months old rootstocks

	A	B	C	General mean
Mean yield (in lb.)	150·08	146·84	138·26	145·04
Mean yield as percentage on general mean	103·44	101·24	95·33	100·00
Standard error	1·86			
Significance	Not significant			

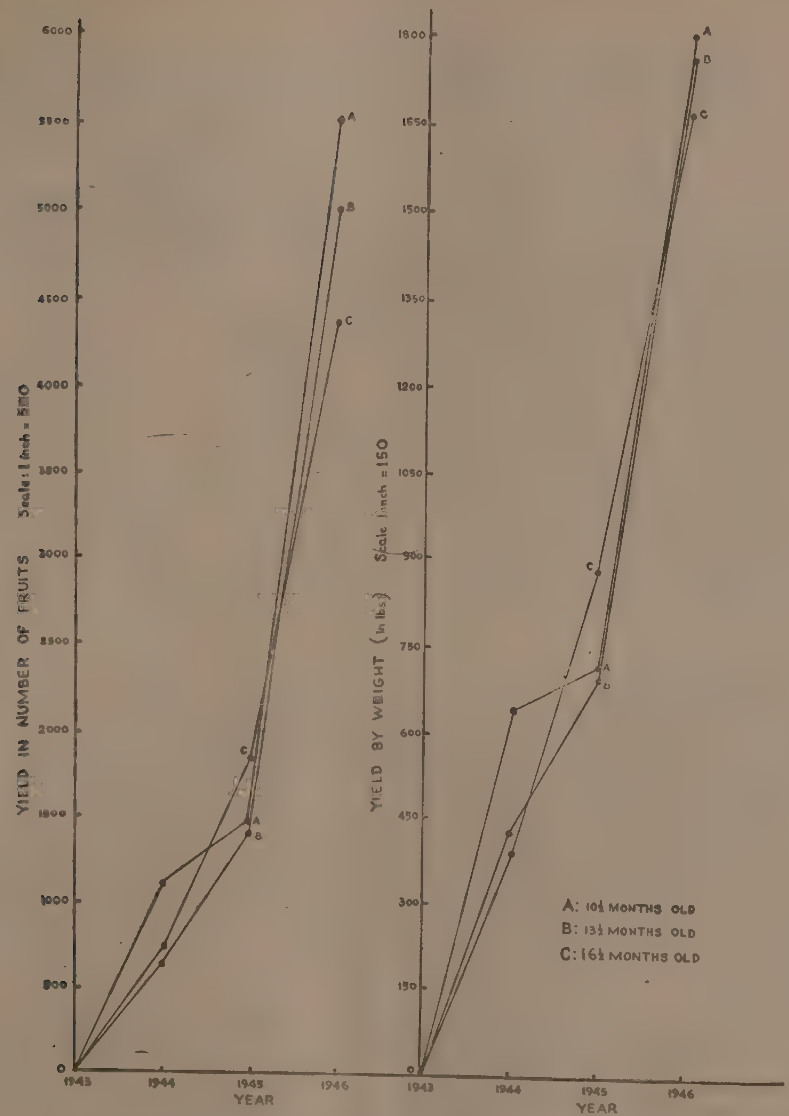

Fig. 3.—Showing the fruit yeilds in Neelum on root stocks of different ages.

It is not to be expected from the above figures and inferences that more widely separated age groups will not show a different reaction. At any rate, within the extensively employed age groups in South India as those included in the trial, it is safe to conclude that larger root stocks will not lead to better orchard performances.

IV. *Compatibility in single and double-worked plants*

In the following Table are summarized the observations collected on compatibility in May 1946, in the trees under the two trials mentioned at the beginning of this paper.

TABLE VI

Showing the extent of compatibility in single and double-worked mango trees

Treatment	Percentage of trees in which			
	Stock stem is outgrown	Intermediate stem has outgrown the ultimate scion	Scion is outgrown	Scion is smooth-jointed
A. Single-worked trees				
1. Neelum inarched	5·56	..	..	94·44
2. Bangalora inarched	61·11	..	..	38·89
3. Neelum root-graft	61·11	..	..	38·89
4. Bangalora root-graft	50·00	..	..	50·00
B. Double-worked trees				
5. Neelum/Bangalora/Seedling	100·00	11·11	11·11	77·78
6. Bangalora/Neelum/Seedling	100·00	5·56	..	94·44
7. Jehangir/Neelum/Seedling	100·00	50·00	..	50·00
8. Himayuddin/Neelum/Seedling	100·00	62·50	..	37·50
9. Alampur Baneshan/Neelum/Seedling	100·00	25·00	..	75·00

It is clear from the fore-going figures that among the single-worked trees, Neelum has so far produced the largest proportion of perfect graft-jointed trees. This, however, need not necessarily mean that in others there is any great incompatibility. As the trees advance in age, the possibility of the scion stems overtaking the stock and intermediate stems by increased pace of growth, cannot be ruled out. It is only on the basis of future observations, therefore, that one can be confident of securing any definite idea on this question of compatibility in these plants. At this stage the only possible inference is that there is no definite incompatibility in any combination, which if had existed should have been reflected on the decline of the scion.

The observations on double-worked plants, however, present certain features which seem to merit a passing mention. Without a single exception the basal rootstock stem in their case has outgrown the intermediate stem. The operation of double-working has, therefore, clearly inhibited the growth and development of the Neelum intermediate stem. But this inhibition of Neelum intermediate stem does not extend to such a length as to prevent the outgrowth of that intermediate piece over the ultimate scion. The reaction of the two component parts *i.e.*, the ultimate scion and Neelum intermediate stem does not seem to be of the same degree. The ultimate scions of Jehangir and Himayuddin have so far been eclipsed by the Neelum base to a very much greater extent than those of Alampur Baneshan and of Bangalora on Neelum intermediate stem. The rate of growth of Neelum double-worked plants on Bangalora is the largest ; so much so that in its case 11·11 per cent of the trees have even outgrown the intermediate. On the basis of smooth unions at the point of double-working also, there is an appreciable difference, Neelum on Bangalora and Bangalora and Alampur Baneshan on Neelum standing out as the best combinations so far. These various features seem to warrant the inference that different combinations react differently in single and double worked trees, but precise knowledge of such relationship is only possible after a long study of orchard performance.

Discussion

An outstanding feature of the Indian mango production is that it is the result of hundreds of varieties. South India alone claims no less than about 400 varieties under cultivation. Orchards planted to a few selected varieties of commercial importance being few and far between, one of the potent means of improvement for the future lies through the restriction of the number of varieties to the most dependable croppers and to those that possess the greatest market value and demand. To this end, variety collections and trials have been established in a number of centres ; and efforts are constantly being made at all these centres to eliminate the less important ones and advocate the most valuable. Connected with this campaign is the work of popularization of top-working the inferior varieties to superior ones of economic value. The operation depends for its success on an understanding of the relationship between the scion variety used for top-working and the variety on which the operation is to be done. Top-working is essentially double-working when it is done on existing grafted trees. If, therefore, the result of top-working any one superior variety over several inferior varieties (each with its own varietal peculiarities, and consequently with different kinds and degrees of response to the ultimate scion) can be determined, it will constitute a valuable step forward and may prevent the loss and disappointment inherent in any indiscriminate top-working campaign. The data produced in this paper from double-working trials serve to emphasize the importance of extended studies in the line. They establish firstly, that double-working with different combinations results in dissimilar growth responses and possibly yield performances as well, though in the later case the data are not sufficient to be conclusive. Secondly, through appropriate selection of scionic combinations it has been shown to be possible to circumvent stock-scion incompatibility. Thirdly, the data seem to show that it is futile to expect increased yields in normally shy-bearing varieties, in which such inherent defects as the existence of a low proportion of perfect flowers, occur.

Almost the same result is indicated from the trial of Neelum and Bangalora trees raised by different propagation methods. Up-to-date, the use of different methods of propagation have had no definite or consistent bearing on the yields of trees, which leads to the surmise that inherent bearing capacity is a dominent factor not subject to material influences by different propagation methods.

It is recognized that a comprehensive picture of the potentialities of seedling root stocks of different age-groups at the time of inarching is not possible at this stage with the material under review. The only information afforded by the present studies is that, with one-year old monoembryonic seedling stock as is now largely used in south of India, it would be best to perform inarching in an optimum season viz.. August. Such trees are shown to perform as well as those propagated vegetatively on older stocks in less favourable months.

Summary

The paper sets out the growth and yield performances of Neelum and Bangalora mango trees propagated by inarching, root-grafting and double-working, and of Jehangir, Himayuddin and Alampur Baneshan trees raised on Neelum intermediate stem piece, as well as of Neelum raised on monoembryonic seedling rootstocks of 10½, 13½ and 16½ months of age at the time of inarching. The performances available for analysis covered only a period of about six years of the early orchard life or three years of bearing period. The data provide the following indications or inferences.

(1) Bangalora is a more rapid and vigorous grower than Neelum among the inarched plants and root-grafts, in terms of scion stem size and tree height.

(2) Double-worked plants in both the varieties are relatively stunted in comparison with the inarched plants and root-grafts, exhibiting smaller tree size or less growth. No perceptible difference has been noted between single worked trees of the scion varieties.

(3) Crop yield by weight of fruits is a more accurate measure of productivity than the yield in terms of number of fruits.

(4) Neelum is inherently less prolific than Bangalora on the basis of fruit weight, although the former has produced larger number of fruits. The inference applies only to young trees as those dealt with in this paper.

(5) Between the propagation methods, no singificant differences are noted with Neelum; while in Bangalora the inarched plants have yielded significantly larger crop weight but not singnificantly larger number of fruits than the double-worked plants.

(6) Jehangir double-worked trees on Neelum intermediates are relatively smaller in size than Himayuddin and Alampur Baneshan trees raised by the same method.

(7) All the three sets of double-worked plants mentioned above are also relatively dwarfed in comparison with single-worked plants, as was already pointed out above in the case of Neelum and Bangalora also. This shows that double-working is definitely dwarfing in effect.

(8) Jehangir has been shown to possess lower cropping capacity than Himayuddin and Alampur Baneshan.

(9) Although there is a strong indication that double-working in these three naturally shy-bearing varieties leads to a higher blossom crop production and precocity, there is no material effect on size of fruit crops, owing possibly to inherent defects as low proportion of perfect flowers in the panicle and partly due to vitiating influences of mango hoppers.

(10) From a trial of the three age groups of rootstocks for Neelum scion, it is found that there is no difference in the orchard performance of the three groups. The inarching of Neelum trees on one year old seedling stocks in an optimum season like August is therefore suggested to be the best.

(11) Smooth graft-joints are a pronounced feature of Neelum inarched trees, while among the double-worked trees the rootstock has prominently out-grown the intermediates.

(12) Through appropriate selections of stionic combinations it seems possible to circumvent stock-scion incompatibility.

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THE DEVELOPMENT OF RED COLOUR IN BLOOD RED MALTA ORANGE (*C. SINENSIS*, OSBECK)

By K. KIRPAL SINGH, M. Sc. (Agri)* Lecturer in Horticulture, Government of India, Department of Agriculture and SHAM SINGH, B.Sc. (Agri.), Ph.D. (Bristol) Fruit Development Adviser to the Government of India, New Delhi

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(With plate VII and one text figure)

THE Punjab plains are pre-eminently suited to the growing of high quality citrus fruits especially the Malta Orange. Its choicest variety—the Blood Red—is much more popular and finds favour with most growers because of its superb quality and the ready sale it commands in the market. The fruit of this variety usually sells at a premium as compared with other varieties of Malta partly because of its unsurpassed quality and partly for the reason that the flesh is tinged red for which the consumer has developed a craze and a fancy.

According to Bonavia [1880], the Blood Red Variety was first introduced in the Punjab at Gujranwala between 1852-56 by Colonel Clarke. For some decades its cultivation remained a mere hobby with a limited number of growers because of the non-availability of genuine nursery trees except at prohibitive rates. Its commercial spread over the province is a matter of the recent past and is the outcome of the efforts of Sardar Bahadur Lal Singh, the then Fruit Specialist, Punjab, and his associates, who arranged large scale supplies of genuine plants of this variety from government sponsored nurseries at nominal price. The sale records of nursery trees of Blood Red variety for the last ten years reveal that 60-80 per cent of the total indents received pertained to this particular variety. This, in itself, speaks for the liking it commands with an average grower all over the province.

The market value of an orange is determined by its quality which is a function of its juice content, colour, texture of flesh, 'rag' content, blend of sugars and acidity and the richness and character of aroma. All these factors collectively determine the taste and flavour of a particular variety. The Blood Red variety possesses these characteristics to a remarkably piquant degree. It has also the added quality of the presence of blood red pigments in its flesh which allures the consumer and account for the premium the fruit commands in the market.

The development of red colour in the flesh of Blood Red variety is not always a matter of certainty. In extent and degree, the red pigmentation varies considerably from year to year, with localities differing in soil-climate complex and even with the fruit borne on one and the same tree. In consequence, this had been rightly regarded as a serious draw-back in this variety for holding an all-out commercial popularity despite its superb quality In view of this uncertain character of Blood Red variety, it had been a matter of common occurrence that a grower accused the nurseryman and the consumer at large accused the fruit dealer when, for reasons already mentioned, the red tinge was found wanting partly or wholly in case of trees supposedly of Blood Red variety or the consignment of fruit of this particular variety.

To probe into the causes leading to this mysterious phenomenon, the investigations were carried out for the first time by Messrs. Lal Singh and A. A. Khan at Lyallpur in the years 1939-40 and 1940-41. The fruit was picked in separate lots from four sections of the trees, *viz.*, north-west, south-west, north-east and south-east and examined for red colour in the flesh. These authors reached the conclusion 'hot rays of the sun falling on the fruit in the afternoon are responsible for poor quality fruit and lack or absence of redness in its flesh'. They, therefore, advised the fruit growers to plant

* Government of India Scholar in Australia

'Jantar' (Sesbania Egyptica) on the south-east and south-west sides of Blood Red trees to provide shade to the fruit borne on these sides in the afternoons in order to obtain better quality fruit. These findings revealed in a general way the correlation between the presence or absence of certain factors for the increase or decrease of red *colouration* but failed to disclose the real cause responsible for colour development and the riddle, therefore, remained unsolved.

Work on citrus rootstock trials in the Punjab [Sham Singh, 1942 and 1944] gave indications that different rootstocks may exert different influences in inducing the red colour in Blood Red variety as this influence was found to be most pronounced when 'Kharna Khatta' was used as the rootstock. Since 'Kharna Khatta' was also found to be incompatible with Blood Red scion [Lal Singh and Sham Singh, 1944], the use of this particular rootstock for inducing the red colour was almost ruled out as a practical proposition.

The clue to the development of red colour in the fruit of this variety of Malta became apparent in an investigation carried out in 1943-44 on the keeping quality of some important citrus fruits as influenced by different rootstocks [Kirpal Singh, 1945]. In view of the indications thus revealed, the work was pursued further in 1944-45 to study exclusively the development of red colour in the Blood Red variety.

Material Used

The material used during 1943-44 consisted of 800 fruits of Blood Red variety brought from the Horticultural Research Sub-station, Montgomery. The fruit was picked in the end of February from eight-year old trees growing on four different rootstocks, namely (i) rough lemon, (ii) 'Kharna khatta', (iii) 'Jullunduri khatti', and (iv) sweet lime. For picking fruits, five trees were selected to represent each treatment. Thus, 200 fruits for each rootstock treatment or 40 fruits from each tree were picked from all the four sides, the top, the bottom and the interior of each individual tree so as to make the composite sample representative of the entire fruit population of a tree.

The material for the next year's work (1944-45) which comprised 200 fruits of Blood Red variety growing on rough lemon rootstock, was obtained from the Risalewala progeny garden, near Lyallpur. This year again, the fruit was picked in the end of February from eight-year old trees growing on rough lemon rootstock. Five trees were selected and forty fruits from each tree were picked in the manner described above.

Methods employed

During the 1943-44 investigations, the project was designed to study the influence of different root-stocks on the keeping quality of citrus fruits. Fruits of Blood Red variety were, therefore, divided into four lots after the rootstock treatments and each lot was further subdivided and placed at two storage temperatures, viz. cold storage (36-39°F) and room temperature storage (62-86° F) at the cold storage laboratory, Punjab Agricultural College and Research Institute, Lyallpur. Twenty-four fruits were employed from each storage temperature for conducting the physico-chemical analysis which were carried out at weekly intervals in case of fruit stored at room temperature and fortnightly intervals in case of fruit stored in the cold storage. Each fruit was cut transversely into two halves and examined for the presence and intensity of red colour.

During 1944-45, 200 fruits of Malta Blood Red variety were stored in the cold storage at temperatures ranging from 32-39°F. For determining the intensity of red colour, 25 fruits were examined at fortnightly intervals in the manner already described above. During this year, the temperature range of the cold storage chamber was intentionally operated between 32-39°F as against 36-39°F of the last year so as to give more effective chills to the fruit during storage.

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Blood Red trees on *kharna khatta*
Note defoliation in all the three trees in the row during winter

(Reproduced from
Indian J. agric. Sci. Vol. 14, Part I)

Results

(1) *The 1943-44 data*

As previously mentioned, the development of red colour in Blood Red variety of Malta as influenced by different rootstocks and storage temperatures was studied in 1943-44. Cut samples of fruit used for the extraction of juice and to carry out the physico-chemical analysis were examined for the presence and intensity of red colour. The results revealed that the colour was most pronounced when the rootstock used was ' kharna khatta '—the order of the various rootstocks in this respect being ' kharna khatta ', rough lemon, ' Jullunduri khatti', sweet lime. There was almost a complete absence of colour when the rootstock used was sweet lime. A quantitative study of the red-tinged fruits in case of Blood Red variety influenced by different rootstocks and storage temperature can be made from the data set out in the following table :

Table I

The influence of different rootstocks and storage temperatures on colour development in Blood Red variety of Malta orange

Rootstock	Percentage of red-tinged fruits at	
	Room temperature storage (62—86°F)	Refrigerated storage (36—39°F)
' Kharna khatta'	35·7	62·5
Rough lemon	19·05	22·9
'Jullunduri khatti '	4·7	14·7
Sweet lime	..	2·3

The figures for the percentage of red-tinged fruits show that the colour development is influenced considerably by the kind of rootstock used. It may be observed further that this individuality of the rootstocks in inducing the red colouration remains unaltered by the variation in storage temperatures. Yet, another point of interest and practical significance is that the percentage of red tinge can be considerably increased by subjecting the fruit to low temperatures. The latter point merits special consideration and attention in that the fruit may be picked when mature and the red colouration induced in the cold storage.

(2) *The 1944-45 data*

In view of the indication received from last year's investigations that low temperature was the factor chiefly responsible for inducing the characteristic red colour in Blood Red variety of Malta, the fruit during the 1944-45 investigation was subjected to a still lower range of temperatures (32-39°F) and the necessary data collected. A study of the increase in the percentage of red tinged fruits as influenced by low temperatures of the storage chamber and the period of storage can be made from the data set out in the following Table :

TABLE II

The influence of the period of storage and low temperature on the development of red colour

Period of storage (weeks)	Percentage of red-tinged fruits
0	56
2	64
4	76
6	88
8	84
10	88
12	92
14	96

The results show that a significant increase in the percentage of red-tinged fruit (from 56 per cent to 96 per cent) can be brought about in 14 weeks when the temperature range of the storage chamber is maintained between 32° and 39° F. This increased inducement in colour is positively the outcome of a temperature lower than that tried in 1943-44. The data further reveal, that although the development of red colour increases with the increase in storage period yet the rate of development is most rapid during the earlier period of six weeks—the percentage of red colour increased by 32 per cent (from 56 per cent to 88 per cent) during this period as against the increase of 8 per cent only during the remaining period of eight weeks.

It is evident that in an investigation of this nature, the sample tested each time would slightly differ from the mean and may, on this account, cause slight variation in results. The slight change in the trend of results after six weeks, storage is evidently due more to the sample variation than anything else. On the whole, it may be concluded that the rate of colour development in Blood Red variety of Malta fruit is associated with the degree and duration of the low temperature to which it is subjected.

It is noteworthy to mention that in addition to the increase brought about in the percentage of red-tinged fruits as a result of low temperature storage, the intensity of colour also increased to a very great extent. Thus, the colour of pulp, which was nearly crimson before the fruit was subjected to low temperature storage, changed to magenta after 14 weeks' storage. [British Colour Council 1938]. This point is also of practical importance in view of the fact that the premium which this variety enjoys over other varieties in the market is mostly due to the intensity of red colour in the pulp.

The Comparison of Data in Tables I and II

The comparison of data in Tables I and II offers interesting observations. In Table I, the percentage of red-tinged fruits in the end of February, 1943-44 in case of rough lemon rootstock was, on the average, 19·05, whereas the corresponding figure in 1944-45 was 56 per cent (vide Table II). This shows that the percentage of red-tinged fruit was nearly thrice as much as that during 1943-44 at the picking time in the end of February. This was evidently the result of favourable winter

temperatures in 1944-45, which were much more severe than those obtaining in the previous year as shown in Table III, below :

TABLE III

Showing the mean minimum and mean maximum winter temperature in 1943-44 and 1944-45

Year	December		January		February		Remarks
	M. Min.	M. Max.	M. Min.	M. Max.	M. Min.	M. Max.	
1943-44 . .	45·0	78·2	41·2	67·1	45·2	70·9	Recorded at Agricultural Station Montgomery
1944-45 . .	42·0	69·2	38·9	63·0	41·6	71·9	Recorded at Agricultural College, Lyallpur

It is evident from the data set out in Table III that the winter months in 1943-44 were much more milder than in 1944-45. Reference to the graph (Fig. I) and appendix Tables I and II would reveal further the fact that the minimum temperature did not go below 35·8°F during 1943-44. On the other hand, it fell below this level on as many as 13 occasions in the following year. On several occasions, the mercury column touched the freezing point and on two occasions it actually went below this level. The frequent occurrence of frosty spells in 1944-45, therefore, resulted in efficient colour development. In other words, the increased colour development in 1944-45 as compared with the 1943-44 crop is correlated with the frequent occurrence of frosty spells during that year. This observation lends support to the popular belief that the Blood Red variety of Malta colours better in certain years and in some localities than in others.

DISCUSSION

The results for the 1943-44 trials indicated the importance of the kind of rootstock for inducing the characteristic red colour development -the influence of 'Kharna khatta' being most marked as compared with the remaining three root-stocks under trial. Since the lower temperature range of the cold storage also favoured colour development as compared with the fruit stored at room temperature, the pronounced difference in favour of 'Kharna khatta' rootstock under orchard conditions is probably associated with the defoliated condition of trees on this rootstock which results even during mild winter months in the Punjab (Plate I). The defoliation offered ideal conditions for the low temperatures of the ripening season to have full play on the exposed fruit. All this explains the reason why colour development is outstandingly better under orchard conditions in case of trees on 'Kharna khatta' rootstock. It also unmistakably leads to the conclusion emerging from the present investigation that the red tinge can be caused and considerably increased under artificial conditions of refrigerated storage. The fruits kept in the cold storage developed a much higher percentage of red-tinged fruits as compared with those stored at room temperature.

The present finding is in conformity with the general notion prevalent amongst fruit growers in the Punjab that fruit of Blood Red variety should not be picked as long as the winter spell of frosty nights is not severe enough to cause colour development to the desired intensity. Since sharp frosts in winter are rare and are experienced after a lapse of three to four years in south-western districts where acreage under the Blood Red variety has considerably increased during the last decade or so, the fruit fails to develop proper colour every year. Even in case of a single tree, the intensity of red colour varies considerably according to the aspect on which it is borne [Lal Singh and A. A. Khan, 1942]. The causes for these variations can be ascribed to the changes in atmospheric temperatures obtaining from year to year and place to place. The results reported by Lal Singh and Khan [1942] indicate beyond doubt that colour development in Blood Red is better on those aspects of the tree which are protected from direct rays of the sun. And these are also the sides where low temperatures of the winter season exert full influence in developing the red tinge.

The effective temperature for the development of red colour appears to be a little above the zero point. The period of exposure of fruit to this temperature determines the degree of development of anthocyanine pigments in the flesh of this variety. These pigments are red coloured bodies and are responsible for the presence of characteristic red colour in Blood Red fruits. The rate of their development is probably accelerated by the accumulation of sugars at low temperatures [Coulter *et al*, 1911].

The present finding has a great practical significance and is a contribution of considerable importance. It has the potential practicability in further enhancing the commercial value of Blood Red variety on the one hand and in widening scope of its profitable marketing on the other. In view of these results, it is immaterial if the winter temperatures in a particular year or locality are not sufficiently severe to develop red colour to the desired intensity. The pickings can be made when the fruit reaches maturity and the colour development perfected under conditions of refrigerated storage. This is a point of immediate commercial significance and great practical economic exploitation for the benefit of trade. In view of this, the vexed problem of uncertainty about the colour development of Blood Red orange under orchard conditions should no longer be attributed as a commercial drawback to this variety.

Summary

1. The factors responsible for the development of red colour in Blood Red orange were studied for a period of two consecutive years at the Cold Storage Laboratories, Punjab Agricultural College and Research Institute, Lyallpur.

2. It has been shown that the development of red colour is markedly influenced by the kind of rootstock used. The rootstocks influencing the colour, arranged in the descending order of magnitude are 'Kharna khatta', rough lemon, 'Jullunduri khatti' and sweet lime.

3. The pronounced difference in favour of 'Kharna khatta' under orchard conditions is probably associated with the defoliated condition of Blood Red trees on this rootstock—the defoliation offered ideal conditions for the low temperatures in the ripening season to have full play on the exposed fruit.

4. The percentage of red-tinged fruits was higher in 1944-45—the year of severe winter months—than that in 1943-44—which passed away without frosty spells.

5. The effective temperature for the development of red colour appears to be a little above the zero point. The period of exposure of fruit to this temperature probably determines the degree of colour development.

6. In view of the results reported, it is immaterial if the winter temperatures in a particular year or locality are not severe enough to cause colour development to the desired intensity under natural conditions. The pickings can be made when the fruit reaches maturity and the colour development can be perfected under conditions of refrigerated storage.

7. The development of red colour in Blood Red Malta fruits will not, however, take place if this vaiety is grown in tracts without having a spell of frosty nights during its ripening period. The vexed problem of uncertainty about colour development should no longer be attributed as a commercial drawback to Blood Red orange.

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APPENDIX—TABLE I

Showing the minimum and maximum temperatures recorded at Agricultural Station, Montgomery from December 1943 to February, 1944

Dates	December, 1943		January, 1944		February, 1944	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1 . . .	45·0	84·5	39·8	70·5	36·5	70·8
2 . . .	44·5	82·0	38·5	73·0	38·0	73·5
3 . . .	42·5	81·0	38·5	72·2	41·2	71·5
4 . . .	42·8	79·8	38·8	72·0	40·0	68·5
5 . . .	41·8	77·2	39·5	63·5	40·5	73·0
6 . . .	42·5	80·0	50·0	66·0	41·0	75·5
7 . . .	37·0	77·5	44·5	70·0	45·2	74·8
8 . . .	41·2	74·5	45·5	59·5	40·0	69·0
9 . . .	41·0	71·5	42·5	60·0	40·0	71·5
10 . . .	44·0	76·5	41·0	61·5	41·0	74·5
11 . . .	45·0	81·0	41·0	63·5	41·5	72·8
12 . . .	46·5	82·2	38·2	60·0	41·8	66·5
13 . . .	50·8	83·2	38·2	66·0	42·2	77·0
14 . . .	46·5	80·2	37·8	68·2	47·5	72·2
15 . . .	46·8	78·5	37·2	67·5	47·5	68·0
16 . . .	46·0	82·2	36·2	69·5	47·5	73·0
17 . . .	45·8	80·0	36·2	70·0	49·5	65·0
18 . . .	46·2	83·2	39·5	74·5	48·2	67·0
19 . . .	48·5	82·8	44·0	75·0	48·0	67·5
20 . . .	49·2	80·5	43·0	73·5	46·0	65·0
21 . . .	48·5	80·0	43·5	71·5	46·0	69·5
22 . . .	48·8	72·0	49·0	66·0	53·0	69·0
23 . . .	47·0	74·5	46·5	65·0	53·0	69·5
24 .	46·5	74·5	47·0	54·5	44·0	62·0
25 .	44·2	75·0	38·0	64·2	46·0	67·0
26	44·0	76·0	38·5	65·0	51·5	73·0
27 .	45·2	76·5	40·5	67·0	57·0	77·0
28 . .	48·0	73·0	45·0	68·2	48·5	79·0
29 .	46·0	73·5	46·5	69·0	49·0	75·0
30 . . .	43·0	75·0	35·8	67·8	..	..
31 . . .	40·5	75·0	36·0	67·0	..	..

APPENDIX—TABLE II

Showing the daily minimum and maximum temperatures recorded at the Agricultural College, Lyallpur for the winter 1944-45

Dates	December, 1944		January, 1945		February, 1945	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1 . . .	47·3	79·0	37·1	66·4	39·1	63·0
2 . . .	47·8	81·8	37·1	67·6	38·7	67·8
3 . . .	48·8	82·0	39·1	56·0	38·9	69·0
4 . . .	49·9	80·6	43·8	63·0	41·7	70·6
5 . . .	48·8	82·0	43·9	46·0	41·1	69·0
6 . . .	45·9	81·9	34·1	49·0	42·1	71·2
7 . . .	46·1	80·0	34·0	56·2	41·1	71·8
8 . . .	48·1	82·0	40·1	54·0	41·1	71·0
9 . . .	52·1	80·5	41·1	48·0	40·6	68·3
10 . . .	48·5	69·7	32·3	52·8	40·9	69·6
11 . . .	43·0	68·7	30·1	53·2	42·9	72·0
12 . . .	39·3	69·8	30·8	52·3	45·4	72·0
13 . . .	40·1	72·2	32·1	56·7	44·4	73·7
14 . . .	40·6	71·0	33·9	57·3	37·1	71·2
15 . . .	36·1	68·5	34·1	65·6	36·1	71·0
16 . . .	36·9	68·0	34·9	67·3	36·3	72·0
17 . . .	32·5	66·0	36·1	69·8	38·1	67·0
18 . . .	32·8	67·5	36·1	70·7	39·1	70·0
19 . . .	34·1	67·8	37·1	64·8	39·1	73·0
20 . . .	34·6	70·0	43·1	71·4	39·1	74·0
21 . . .	45·1	56·1	43·1	70·8	39·9	76·0
22 . . .	43·1	64·0	43·1	74·0	40·8	76·3
23 . . .	41·3	70·8	45·9	70·3	41·9	77·0
24 . . .	38·1	71·7	48·8	70·0	43·1	79·7
25 . . .	35·9	68·8	43·1	71·0	45·1	79·8
26 . . .	36·1	66·2	43·1	70·8	50·1	78·0
27 . . .	39·3	64·0	40·1	71·0	52·4	66·6
28 . . .	48·8	60·0	41·1	71·7	49·8	73·6
29 . . .	41·3	67·8	43·9	68·7	..	..
30 . . .	41·8	70·7	44·9	65·8	..	..
31 . . .	39·1	67·0	37·8	60·7	..	..

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